Natural mineral hackmanite demonstrates highly repeatable color change ability

June 21 2022

Hackmanite turns purple under UV irradiation, and the color fades back to white in a few minutes under regular white light. This sample is from Greenland. Credit: Mika Lastusaari

While investigating hackmanite, researchers found that it can change color upon exposure to UV radiation repeatedly without wearing out. The results show that the inexpensive hackmanite, which is easy to synthesize, also has high durability and multiple applications.

A research group at the University of Turku, Finland, has been investigating and developing the properties of the hackmanite for almost a decade. Applications such as personal UV monitoring and X-ray imaging have been developed based on hackmanite's ability to change color.

Hackmanite changes its color from white to purple under UV irradiation and eventually reverts back to white if no UV is present. The structural features enabling such repeated changes have so far been unclear. Now, upon investigating three natural minerals—hackmanite, tugtupite and scapolite—the researchers have found the answer.

These color-changing minerals are inorganic natural materials, but there are also organic compounds, hydrocarbons, that can change color reversibly due to exposure to radiation. These hydrocarbons, however, can only change color a few times before their molecular structure breaks down. This is because the color change involves a drastic change in the structure, and undergoing this change repeatedly eventually breaks the molecule.

"In this research, we found out for the first time that there is actually a structural change involved in the color change process, as well. When the color changes, sodium atoms in the structure move relatively far away from their usual places and then return back. This can be called 'structural breathing,' and it does not destroy the structure even if it is repeated a large number of times," reports Professor Mika Lastusaari from the Department of Chemistry at the University of Turku, Finland.

White scapolite turns blue under UV irradiation. The coloration and reversion back to white after the removal of the UV source take only a few seconds, because atoms in the structure move short distances. Scapolite is a rather common mineral. This sample is from Afghanistan. Credit: Sami Vuori

Researchers proved that hackmanite's ability to alternate between white and purple forms is highly repeatable

According to Professor Lastusaari, the durability is due to the strong three-dimensional cage-like overall structure of these minerals, which is similar to that found in zeolites. In detergents, for example, the cage-like structure enables zeolite to remove magnesium and calcium from water by binding them tightly inside the pores of the cage.

"In these color-changing minerals, all processes associated with the color change occur inside the pores of the zeolitic cage where the sodium and chlorine atoms reside. That is, the cage-like structure allows atomic movement inside the cage while keeping the cage itself intact. This is why minerals can change color and revert back to their original color practically indefinitely," Doctoral Researcher Sami Vuori explains.

Previously, it has been known that scapolite changes color much faster than hackmanite, whereas tugtupite's changes are much slower.

"Based on the results of this work, we found out that the speed of the color change correlates with the distance that the sodium atoms move. These observations are important for future material development, because now we know what is required from the host structure to allow the control and tailoring of the color change properties," says Doctoral Researcher Hannah Byron.

"There were no characterization methods available for the research on color changing minerals, which is why we have developed new methods by ourselves. However, it is difficult to interpret the results unambiguously based on experimental data alone. In fact, we could not have reached the present conclusions without strong support from theoretical calculations, since only the combination of experimental and computational data shows the whole picture. We owe a great many thanks to our collaborator Professor Tangui Le Bahers and his group, who have developed and advanced suitable computational methods to such detail and accuracy that would not have been possible just a few years ago," says Lastusaari.

Tugtupite is a rare mineral, which turns pink when exposed to UV radiation. The return back to white takes several hours, because it requires large atomic movements. This sample is from Greenland. Credit: Sami Vuori

Hackmanite has amazing potential for applications

The Intelligent Materials Research Group at the Department of Chemistry of the University of Turku, led by Lastusaari, has long conducted pioneering research on materials with light and color-related properties, especially on hackmanite. They are currently exploring numerous applications for hackmanite, such as possibly replacing LEDs and other light bulbs with the natural mineral and using it in X-ray imaging.

One of the most interesting avenues that the researchers are currently exploring is a hackmanite-based dosimeter and passive detectors for the International Space Station, intended to be used to measure the radiation dose uptake of materials during space flights.

"The strength of hackmanite's color depends on how much UV radiation it is exposed to, which means that the material can be used, for example, to determine the UV index of Sun's radiation. The hackmanite that will be tested on the space station will be used in a similar fashion, but this property can also be used in everyday applications. We have for example already developed a mobile phone application for measuring UV radiation that can be used by anyone," explains Sami Vuori.

The paper was published in June in the *PNAS* journal.

More information: Pauline Colinet et al, The structural origin of the efficient photochromism in natural minerals, *Proceedings of the National Academy of Sciences* (2022). DOI: 10.1073/pnas.2202487119

Provided by University of Turku