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Is it light or humidity?

Montserrat Capellas Espuny

What makes emerald green fade in famous paintings? Scientists at ESRF study how colours fade.

The following was adapted from an ESRF News article.

Why do some bright green areas in 19th-century paintings turn dull, crack, or even flake away? For years, conservators had suspected that the once popular pigment emerald green might be to blame. Now, scientists have identified exactly how light and humidity trigger its degradation.[1]

A brilliant but unstable pigment

During the 19th century, advances in industrial chemistry led to the creation of new synthetic pigments.[2] One of the most striking was emerald green, a vivid copper arsenite compound that is prized for its intense colour.

Artists such as Paul Cézanne, Claude Monet, Vincent van Gogh, Edvard Munch and Robert Delaunay used this pigment in their works.[1] However, some artists noticed that the colour did not remain stable over time. Green areas could darken, lose their brilliance, or develop surface cracks. Later, scientists confirmed that emerald green is highly toxic due to its arsenic content.[3] But what exactly causes this deterioration?

Investigating a mystery in the museum

To answer this question, researchers from several European institutions examined both laboratory paint samples and

Left: Prof. Aldo Romani (University of Perugia, CNR-SCITEC) prepares the visible hyperspectral imaging system for the scientific investigation of The Intrigue (1890, Royal Museum of Fine Arts Antwerp (KMSKA)) by James Ensor during the MOLAB/E-RIHS campaign. Right: Visible hyperspectral imaging from the MOLAB/E-RIHS platform positioned for analysis of James Ensor's The Intrigue (1890, Royal Museum of Fine Arts Antwerp -KMSKA)
Image courtesy of CNR-SCITEC, University of Perugia, MOLAB/E-RIHS

real artworks. A key case study was The Intrigue (1890) by James Ensor, housed at the Royal Museum of Fine Arts in Antwerp.[1]

First, scientists performed non-invasive measurements directly on the painting. Using portable instruments provided by the University of Antwerp and the European mobile heritage science laboratory, MOLAB, they analysed the green areas without removing any material. These measurements helped them to identify where to take microscopic samples for further study.

The tiny samples were then analysed using synchrotrons at large-scale research facilities, including the European Synchrotron Radiation Facility (ESRF) and the German Electron Synchrotron (Deutsches Elektronen-Synchrotron, DESY) in Germany. Synchrotrons produce extremely bright X-rays, enabling scientists to identify chemical compounds at micrometre and even sub-micrometre scales.

Researcher Annelies Rios Casier (University of Antwerpen) taking a microsample of the emerald green paint layer of The Intrigue (1890, KMSKA) by James Ensor
Image courtesy of Lies Vanbiervliet

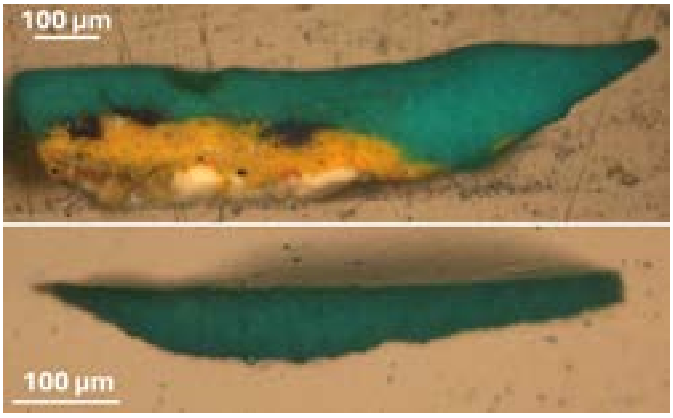
As artists' paints are chemically complex mixtures, the team employed several techniques, including X-ray diffraction and X-ray absorption spectroscopy. This multi-method approach allowed the team to determine how arsenic changes form within the paint layers.

Left: Macro X-ray Powder Diffraction (MA-XRPD) scanner from the ARCHES and AXIS research group at the University of Antwerp, in front of The Intrigue (1890, KMSKA) by James Ensor. Right: Nozzle of the Macro X-ray Fluorescence (MA-XRF) scanner positioned close to the paint surface of the image.
Image courtesy of Annelies Rios Casier

Light versus humidity

The researchers discovered that light and humidity affect emerald green in different ways.[1] Humidity promotes the formation of arsenolite (As_2O_3), a crystalline arsenic compound. This makes the paint brittle and prone to flaking. Light triggers a chemical reaction in which arsenic is oxidised from a trivalent to a pentavalent state. This reaction produces a thin, whitish surface layer that dulls the original green colour.

When the team compared artificially aged laboratory samples with microscopic cross-sections from the aforementioned study (The Intrigue), they found strong similarities. The results indicate that photo-oxidation (i.e. degradation caused by light) poses the greatest long-term threat to the paintings.



Photomicrographs of the paint fragments sampled from two altered emerald green-based areas of The Intrigue (1890, KMSKA) by James Ensor and analyzed by vibrational spectroscopic techniques and synchrotron radiation X-ray methods at the ESRF and PETRA III-DESY.

Image courtesy of ESRF and DESY

Implications for conservation

The study also highlights an important practical point: visual inspection alone is not sufficient to assess the condition of emerald green paint. Subtle chemical changes may occur before dramatic colour shifts are visible.

The researchers demonstrated that 'external reflection infrared spectroscopy' can be used directly in museums to non-invasively detect pentavalent arsenic compounds. This technique helps conservators to identify areas at risk and determine when micro-sampling and more advanced X-ray analyses are necessary.

Understanding the chemistry of historical pigments not only helps preserve cultural heritage, but also provides an opportunity to connect art, chemistry, and material science in the classroom.

What we see at the ESRF

At ESRF, the scientists used two key X-ray techniques on tiny samples of emerald green taken from the painting:

- X-ray diffraction (XRD): This technique reveals the crystal structure of minerals and compounds. When X-rays hit a structured material, they bounce off in specific patterns. By recording these patterns, scientists can tell whether a pigment has stayed the same, or whether new crystals (like degradation products) have formed.[4]
- X-ray absorption spectroscopy (XAS): This method tells researchers about the chemical state of a specific element – in this case, arsenic. By measuring how X-rays are absorbed at very precise energy levels, scientists can see whether the arsenic atoms are in a less (as in fresh emerald green) or more (as in degraded paint) oxidised state. It's like checking an element's 'chemical fingerprint'.[5]

Together, these techniques allow scientists to map the composition of paint layers at tiny scales and identify subtle changes that can't be seen with the naked eye.

Left: Infrared spectrometer from the MOLAB/E-RIHS platform positioned for analysis of James Ensor's The Intrigue (1890, KMSKA). Right: Researcher Sara Carboni Marri (University of Perugia, CNR-SCITEC) performing infrared spectroscopy analysis on an emerald green area of James Ensor's The Intrigue (1890, KMSKA) during the MOLAB/E-RIHS campaign.

Image courtesy of CNR-SCITEC, University of Perugia, MOLAB/E-RIHS

References

[1] Carboni Marri S et al. (2025) Discovering the dual degradation pathway of emerald green in oil paints: The effects of light and humidity. *Science Advances* **11**. doi: 10.1126/sciadv.ady1807

[2] A downloadable handbook describing the history, characteristics, and scientific analysis of 10 artists' pigments: https://www.nga.gov/research/publications/artists-pigments-handbook-their-history-and-characteristics-volume-3

[3] Russick S et al. (2025) Toxic Tales: Arsenic's Legacy in Nineteenth-century Green Book Bindings at Northwestern University Libraries. *Studies in Conservation* **70**: 745–761. doi: 10.1080/00393630.2025.2460403

[4] X-ray diffraction explained: https://www.esrf.fr/home/UsersAndScience/Experiments/ID19/Techniques/Diffraction/Overview.html

[5] X-ray absorption spectroscopy explained: https://www.esrf.fr/UsersAndScience/Experiments/CRG/BM14/Xafs

Resources

- Learn how high-tech science can be applied to the study of ancient art and famous paintings: Capellas Espuny M (2019) Art and science from Pompeii to Rembrandt. *School* **48**: 20–22.
- Art inspired by molecular biology: Gupta D, Armstrong D (2021) Bringing the beauty of proteins to the classroom: the PDB Art Project. *Science in School* **54**.
- Why is Van Gogh's brilliant yellow turning brown? Brown A (2011) Van Gogh's darkening legacy. *Science in School* **19**: 19–25.

AUTHOR BIOGRAPHY

Montserrat Capellas Espuny is the editorial content manager at the ESRF, where she has worked for more than 20 years.