Elements
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MINERALS, PHYSICS, AND CHEMISTRY—A DIFFUSE BOUNDARY

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Sumit Chakraborty

The highest academic degree that most readers of this issue would be familiar with is a PhD—Doctor of Philosophy. Independent of whether the field of research of the person earning the degree lies in the sciences, humanities, social sciences, engineering, or any other branch of intellectual inquiry, the degree is the same. This reflects the commonality of scholarly depth, critical analysis, and new perspectives that underlie the degree in any field that has a place in a university, which itself is governed by the principles of *Universitas* (a Latin word meaning the whole). Boundaries between disciplines came into place much later, largely for organizational reasons. Even when they did, the early divisions had quite a different emphasis from what we are familiar with today. For example, Figure 1 from a famed ceiling at the Library of Congress at Washington DC places geology on equal footing with physics, chemistry, and mathematics as branches of science (with astronomy occupying a central position for historical reasons). This leads one to ponder where the boundaries lie—when is physics or chemistry used to learn about minerals, and when does the study of minerals advance physics or chemistry (the boundary between which themselves is often diffuse).

Figure 1 Mosaic of the Sciences in the Jefferson building of the Library of Congress in Washington, DC (USA). Photo: Sumit Chakraborty.

The mineral pitchblende (uraninite, UO$_2$) was found to be much more radioactive than pure uranium. The study of this phenomenon led Marie and Pierre Curie to the discovery of two entirely new chemical elements—radium and polonium—and subsequently to the Nobel Prize in Chemistry for Marie in 1911.

In 1827, Robert Brown discovered the eponymous random motion of tiny particles while studying pollen under a microscope. However, the observation itself was open to multiple interpretations—it could be something biological related to life, or it could be something physical. The decisive information came from the study of fluid inclusions in quartz. Feynman, in his celebrated lecture notes in physics, describes the situation as follows: “*In fact he helped to demonstrate that this had nothing to do with life by getting from the ground an old piece of quartz in which there was some water trapped. It must have been trapped for millions and millions of years, but inside he could see the same motion. What one sees is that very tiny particles are jiggling all the time.*” Understanding the phenomenon had to wait almost a century, until 1905–1906, when Albert Einstein and Marian Smoluchowski independently and through alternate approaches provided the explanation that led to not only the demonstration that molecules exist, but also to a pathway for the measurement of the Avogadro number. Indeed, that publication, one in the series that constituted the *annus mirabilis* (roughly, miraculous year) of Einstein in 1905 (others include the photoelectron effect for which he won his Nobel Prize, and the theory of special relativity with the famed $E = mc^2$ equation), was the topic on which Einstein obtained his PhD and, notwithstanding the reputation of the other studies, led to arguably the most widely used equation ever—the diffusion equation, which leads to the relationship $x^2 \sim Dt$. That relationship finds applications in physics, chemistry, biology, mineralogy–petrology–geochemistry, materials science, ecology, geomorphology, and even in financial models of the stock market (e.g., the Black-Scholes equation).

A final example may help to underscore the two-way channel between geology and physics/chemistry. When Napoleon went on his expedition of Egypt in 1798, one of the scientists he chose to accompany him was Claude-Louis Berthollet. Berthollet knew from his laboratory experience that sodium carbonate reacted with calcium chloride to produce a saline (NaCl) solution and precipitate calcium carbonate. On the expedition, he observed sodium carbonate forming from reaction of water with limestone, i.e., the reverse of the laboratory reaction, in the famous natron lakes in the Nile Valley (enclosed bodies of water that were famous because sodium carbonate was mined from ancient times, among other reasons, for mummification). This led him to propose that reactions can go both ways depending on conditions (e.g., concentrations of different reactants and products), which then led to the law of mass action and the concept of the equilibrium constant—a quantity that has gone on to form the backbone of industrial chemistry and chemical engineering. The details of Berthollet’s study reveal that it was an exquisite geochemical field study. For example, he used observations in a single lake where sodium chloride was forming in one part and sodium carbonate in another (the water from the two parts were not communicating with each other); in other areas, there were alternating layers of carbonate and chloride,

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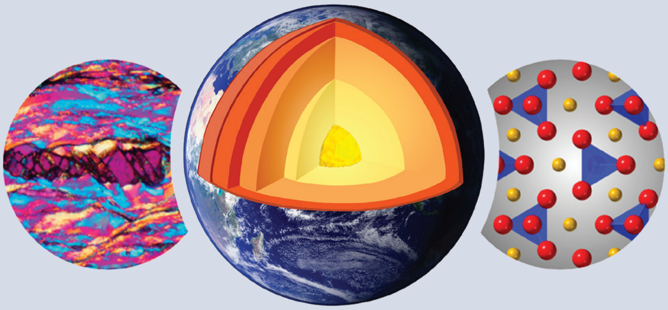
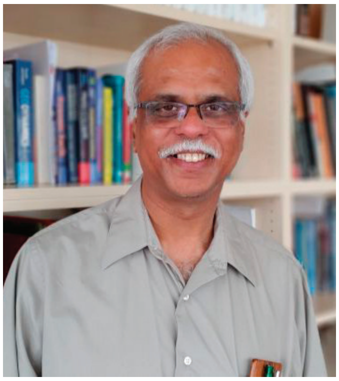
ABOUT THIS ISSUE

Understanding the physical and transport properties of minerals is essential for deciphering geophysical and planetary processes. Building on Haüy's early recognition of the link between crystal structure and macroscopic behavior, modern spectroscopic, thermal, mechanical, electrical, and magnetic techniques now probe these properties across all scales—from atoms to planets. This issue of *Elements* explores how minerals respond to external fields, revealing clues about their past and the dynamic processes shaping Earth and other planetary bodies. It presents key concepts in mineral physics alongside recent technological advances that enhance our ability to study planetary interiors. Through selected research areas, the volume illustrates how this knowledge deepens our understanding of planetary evolution and highlights the major scientific challenges that lie ahead.



(LEFT) Cataclastically deformed garnet surrounded by recrystallized quartz. IMAGE CREDIT: CLAUDIA TREPMANN. (RIGHT) Crystal structure of olivine.

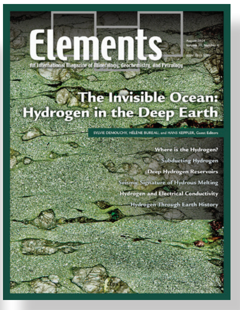
THANK YOU, SUMIT CHAKRABORTY

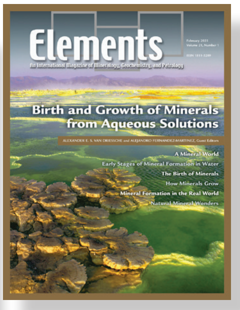


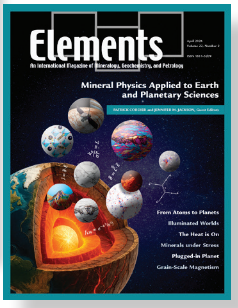
This fascinating thematic issue of *Elements* marks the sixth and final issue published under the leadership of Principal Editor of Mineralogy, Professor Sumit Chakraborty (Ruhr Universität Bochum, Germany). It has been both an honor and a pleasure to have Sumit serve on the *Elements* Editorial Board. His knowledge, insight, kindhearted dedication, and fine-tuned attention to detail have strengthened the magazine's standards for excellence in ways that will continue to positively influence the publication for years to come. In addition to his service as Principal Editor, Sumit also played a key role in *Elements*' 20th anniversary commemoration at Goldschmidt 2025 in Prague, Czech Republic, where he organized and chaired the Special Session, "*Elements* at 20 Years: Past Successes and Future Directions," which included a Town Hall that facilitated forward-looking discussions on the future of the publication.

Since joining the Board in 2023, Sumit has overseen the publication of "**Extraterrestrial Organic Matter**" (February 2024, vol. 20, no. 1), "**The Invisible Ocean: Hydrogen in the Deep Earth**" (August 2024, vol. 20, no. 4), "**Birth and Growth of Minerals from Aqueous Solutions**" (February 2025, vol. 21, no. 1), "**Sample Return Through the Ages**" (October 2025, vol. 21, no. 5), "**Earth's Carbon Thermostat: Beyond the Textbook Model**" (February 2026, vol. 22, no. 1), and the present issue "**Mineral Physics Applied to Earth and Planetary Sciences**" (April 2026, vol. 22, no. 2). These elegantly curated collections of review papers on fundamental topics in the geosciences will continue to serve and support students, researchers, educators, and policymakers as educational resources for generations to come. Please join us in thanking Sumit—as well as the more than 100 authors and editors he has coordinated—for this tremendous contribution to the geoscience literature and community. We wish Sumit all the very best in his future endeavors, both personal and professional, and look forward to seeing his name again soon in the pages of *Elements*.

Tom Sisson, **Carol Frost**, **Penny King**,
and **Esther Posner**







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there were seasonal variations, and most importantly—the carbonate was forming where the bedrock was limestone, but not where it was shale. It was in the context of these geological observations and spatial and lithological context of the chemical reactions that he could come up with the idea of reversibility of chemical reactions.

One could continue with the list of studies of natural materials that have yielded fundamental advances in physics and chemistry. In all of these cases, it is the study of those materials with an awareness of the current state-of-the-art in physics and chemistry that led to the important breakthroughs. This issue of *Elements* deals with the applications of principles of physics to study minerals and inform us about geological processes. This is a topic that has become a major field of research in mineral sciences, but it is not taught as such in typical undergraduate Earth science curricula. The chapters in this issue attempt to convey some of the exciting developments in the field through the lens of five of the classical branches of physics—mechanics, heat, light, electricity, and magnetism. The hope is that it will attract more scientists to the interface of physics and minerals, point them toward the state of the art, and encourage them to transcend traditional disciplinary boundaries in general.

Sumit Chakraborty
Principal Editor