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Editorial

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High-pressure chemistry

***Communications Chemistry* is pleased to present a Collection of articles from across the broad field of high-pressure chemistry. Here, Editorial Board Member Dr James Walsh introduces the topic and takes us on a tour of the Collection content.**

In *The Diamond Maker*, a short story by Wells published in 1894[1], the narrator is enjoying a quiet evening on the embankment of the River Thames when he is approached by a stranger, who after making some small talk pulls from his pocket a diamond as large as any that was known at the time. He then claims to have synthesised the enormous diamond using a new method he has developed that involves sealing a mixture of rocks and explosives within a steel cylinder and heating the whole thing in a fire. The narrator is skeptical, in part because the man looks as though he has been "left in a dust-bin for a week" (presumably this did not comport with how solid state chemists carried themselves in the late nineteenth century), but mainly because the chemical synthesis of diamond had at that time a reputation as a highly lucrative but wholly unyielding challenge. Scientists had used geological clues to deduce that diamonds came from deep within the earth and thus knew that enormous pressures and temperatures were probably required, but experimentalists simply had no way to access such conditions in the laboratory.

It was six decades after Wells' story was first published that diamond was eventually synthesized by Hall using his "belt" apparatus capable of reaching 10 GPa[2], achieving what many before him had devoted entire careers to, and helping to spur the development of high-pressure experimentation over the following decades into the far-reaching discipline that it has become today. Indeed, the increasing commercialisation of the tools and instrumentation required for subjecting samples to extreme pressures has made such experiments more accessible than ever to researchers, and has fed the sustained flourish of high-pressure methods across the full range of scientific disciplines. In this Collection, we aim to showcase how high pressure has impacted research within chemistry specifically.

High-pressure geo- and biochemistry

We begin our tour of this Collection in the depths of the ocean, where crushing pressures can affect how life operates at a cellular level. To better understand how organisms have adapted to survive in deep sea hydrothermal vents, Osborn Popp et al. report on a novel methodology that allows solid state NMR to be carried out at pressures up to 30 MPa, showing how it can be used to study ways that organisms could be modulating their membrane fluidity under extreme pressures and temperatures (https://doi.org/10.1038/s42004-025-01449-7)[3]. These so-called piezophillic adaptations can also be found in larger marine life. For example, the cells of fish that live kilometres beneath the ocean's surface are found to contain a higher concentration of molecules that protect against pressure-induced damage (e.g. protein denaturation). Laurent et al. report on the effects that one such protectant, trimethylamine N-oxide, has on the structure of water up to 4 kbar (0.4 GPa) (https://doi.org/10.1038/s42004-022-00726-z)[4].

Breaking through the floor of the deep oceans and heading down into the upper mantle of the planet, Zhang et al. study micron-scale pockets of fluids found trapped within natural subduction zone samples that provide direct evidence for immiscible methane–water phases at pressures of around 1.3–2.1 GPa and suggest a new mechanism for the transfer of carbon into the mantle (https://doi.org/10.1038/s42004-024-01355-4)[5]. Secchiari et al. examine the cycling of volatile elements at similar depths within the Earth using a novel ex situ method that enables quadrupole mass spectrometry on microlitre quantities of sulfur-bearing fluids synthesised within the laboratory at pressures of 3 GPa (https://doi.org/10.1038/s42004-024-01370-5)[6]. Taking us deeper into the Earth, to the region where the upper mantle transitions into the lower mantle, Spahr et al. report a novel pyrocarbonate synthesized with laser heating in the diamond anvil cell at 20 GPa that sheds light onto the fate of subducted carbonates in the Earth's deep carbon cycle (https://doi.org/10.1038/s42004-024-01293-1)[7]. Katsura presents a Review of the complex phase relations of bridgmanite, the most abundant mineral in the Earth's lower mantle (https://doi.org/10.1038/s42004-024-01389-8)[8], while Akaogi et al. present a Review of the post-spinel AB_2O_4 structures adopted by numerous minerals across the entirety of the Earth's mantle (https://doi.org/10.1038/s42004-024-01278-0)[9].

On our return back to the Earth's surface, we follow the path taken by so-called "super deep" diamonds that form or recrystallise at depths of up to 600–700 km, bringing with them impurities (or "inclusions") that provide a direct sampling of the Earth's mantle. Alvaro et al. provide a Comment on the wealth of information that these inclusions can provide about the Earth's interior and its history (https://doi.org/10.1038/s42004-022-00627-1)[10].

Structural and mechanical properties at high pressure

A core challenge in high-pressure chemistry is to understand how and why certain phases undergo phase transitions under compression. Although density is clearly a major driving force in the stabilisation of one structure over another at a given pressure, it is impossible to ignore the effects that arise from chemical bonding interactions between atoms, which can lead to surprising complexity in otherwise simple systems. Illustrating this, Ranieri et al. present a detailed mapping of the phases exhibited by NH_4F under extreme compression (https://doi.org/10.1038/s42004-024-01309-w)[11], while Ukoji et al. present a high-pressure study into K–Ag binary intermetallic compounds, delving deep into the electronic structure of three phases to better understand the driving forces behind their stability (https://doi.org/10.1038/s42004-024-01245-9)[12]. Zhang et al. show how a novel $P2_1/c$ polymorph of $CsPbBr_3$ can be accessed under high pressures (https://doi.org/10.1038/s42004-024-01265-5)[13], and Buckingham et al. investigate the pressure stability of high entropy metal chalcogenides for the first time (https://doi.org/10.1038/s42004-025-01463-9)[14].

Emphasising the point that even conceptually simple systems can exhibit remarkable structural complexity under pressure, Loerting et al. provide a Comment on the 19 (and counting) different forms of water ice currently known (https://doi.org/10.1038/s42004-020-00349-2)[15]. Sticking with water ices, Karina et al. demonstrate how even the amorphous ices are holding onto secrets, as they report a high pressure cryogenic study into the stability field of competing phases characterised by differences in their densities (https://doi.org/10.1038/s42004-025-01480-8)[16]. Further demonstrating the complexities that can be hidden within amorphous phases, Masai et al. show how pressure can be used to access novel topologies of amorphous silicas by subjecting crystalline zeolites to cold compression (https://doi.org/10.1038/s42004-023-01075-1)[17].

Pulling the curtain back on the often-ignored effects of non-isotropic compression, Yang et al. show how non-hydrostatic stress can induce metallization of ZrS_2 at significantly lower pressures than those required with hydrostatic compression, demonstrating how an understanding of deviatoric stresses is critical for a more complete understanding of materials properties (https://doi.org/10.1038/s42004-024-01223-1)[18]. Lastly, Son et al. add to the growing trend of measuring the bulk moduli of metal–organic frameworks to better understand how their compressibility is tied to framework flexibility (https://doi.org/10.1038/s42004-023-00981-8)[19].

High-pressure synthesis and characterization

High pressure is a uniquely powerful tool in solid-state synthesis because it can completely alter the relative thermodynamic stability of different crystal structures, providing synthetic access to undiscovered phases and expanding families of known phases. Kovalev et al. demonstrate how new phases remain undiscovered even in very well studied systems, reporting on the high-pressure synthesis of a novel iron carbonate formed from laser heating in the diamond anvil cell at around 65 GPa (https://doi.org/10.1038/s42004-025-01450-0)[20]. Neziraj et al. present the synthesis of a novel hydrogen-stabilized $Mg_5Bi_3H_x$ Zintl phase at relatively low pressures of just 4 GPa (https://doi.org/10.1038/s42004-025-01530-1)[21].

One of the most exciting aspects of high-pressure synthesis is that it can coax chemical reactivity from elements and phases that have a reputation for stability. In their Comment, Miao et al. provide an outline of the surprising chemical reactivity of the noble gases, including their ability to stabilise novel compounds without forming chemical bonds in the traditional sense (https://doi.org/10.1038/s42004-022-00631-5)[22]. Yin et al. then report on the remarkable chemical reactivity of NaCl and KCl under high pressures, detailing the synthesis of novel yttrium and dysprosium chlorides and chloride carbides at pressures up to 160 GPa (https://doi.org/10.1038/s42004-022-00736-x)[23].

To shed light on how diamonds can be synthesised with bottom-up approaches, Tang et al. present results from Monte Carlo simulations that examine how bulk diamond forms from hydrogen-terminated molecular species containing carbon skeletons that are isostructural to nanodiamond— so-called "diamondoids" (https://doi.org/10.1038/s42004-024-01261-9)[24]. They find that higher diamondoid molecules, which contain larger carbon skeletons, form larger bulk diamond crystals and with fewer vacancies.

Finally, we close with a Perspective by Hu et al. that examines how dynamic compression is opening up a new route for the laboratory synthesis of quasicrystals (https://doi.org/10.1038/s42004-024-01319-8)[25]. They describe how gas guns have been used to shoot flyer plates into samples at speeds up to 7 km/s in order to induce peak stresses on the order of 20–30 GPa. The near instantaneous rise and fall of pressure (and temperature) during the shock propagation through the sample leads to highly non-equilibrium conditions from which exotic phases such as quasicrystals can be accessed and recovered.

Outlook

The field of high pressure science is experiencing a period of explosive growth across many subdisciplines of chemistry, spurred by the expanding access to the tools and instrumentation required to study matter under extreme conditions. The articles featured in this Collection are a testament to the incredible breadth of discoveries made possible with high pressure techniques, and we hope they inspire chemists to think about how high-pressure experiments could drive forward their own areas of research.

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Competing interests

The author declares no competing interests.