Matter and
Radiation at Extremes

EDITORIAL

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2022 HP special volume: Interdisciplinary high pressure science and technology

Cite as: Matter Radiat. Extremes 8, 063001 (2023); doi: 10.1063/5.0181097
Submitted: 14 October 2023 • Accepted: 15 October 2023 •
Published Online: 2 November 2023

View Online Export Citation CrossMark

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Note: This paper is part of the Special Topic Collection on High Pressure Science 2022.
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https://doi.org/10.1063/5.0181097

High pressure science and technology is a vast area of interdisciplinary research that encompasses the fields of physics, chemistry, geoscience, and materials science and in which the science of ordinary matter is only a special case under ambient conditions. Pressure, the physical variable of force exerted on the chemical bonding of a material, directly controls the material's physical and chemical properties, in a way that can create materials with great potential for practical application as well as revealing surprising behaviors of the interiors of the Earth and other planets that are entirely under pressure. Generation of high pressures and probing of the enormous pressure-induced changes in crystal chemistry, bonding energy, electron–phonon–photon couplings, electro–magnetic interactions, etc. both require interdisciplinary technological developments. The present *2022 MRE HP Special Volume* provides a snapshot of ongoing multidisciplinary advances.

Chemical searches for high-energy-density materials (HEDMs) have traditionally focused on the design and synthesis of nitrogen-rich compounds with a high ratio of chemical energy output to density (thrust-to-weight ratio). Physical compression favors the formation of single-bonded nitrogen and opens a fertile new ground for the production of HEDMs. Lin *et al.*[1] report an aromatic alkaline-earth nitride $P_{4/nmm}$-BeN$_4$ with square planar N_4^{2-} rings and high energy density (3.924 kJ/g). Analyses of enthalpy of formation and stability indicate that $P_{4/nmm}$-BeN$_4$ can be synthesized under pressures above 31.6 GPa and recovered to ambient condition. The transfer of outer-shell *s* electrons from the Be atom to the N_4 cluster and the accommodation of lone-pair electrons in the outer-shell 2*p* orbital of N_4^{2-} contribute to the stability of BeN$_4$. The prediction of a series of metal nitrides with chain-like polynitrogen through the use of machine learning and graph theory has the potential to revolutionize the field of HEDMs. According to Yuan *et al.*,[2] some polymorphic nitrogen compounds should be energetically and dynamically stable below 40.8 GPa. The presence of polymerized N_4 chains enables these metal nitrides to store a large amount of energy. Additionally, these compounds exhibit high detonation pressures and velocities, outclassing traditional explosives like TNT and HMX.

The recent boom in pressure-induced superconductivity with critical temperature T_c above 200 K[3–5] is a by-product of chemical short-cuts to physical quests for metallic hydrogen and room-temperature superconductivity. β-UH$_3$ is a precursor of uranium-based hydrogen-rich superconducting materials, and it plays an important role in the fields of nuclear technology and hydrogen storage materials. Wu *et al.*[6] have investigated the electronic properties of β-UH$_3$ up to 75 GPa using the first principles DFT+U formalism. Their findings provide a new understanding of the exotic features of 5*f* electrons under high pressure. Bonding unsaturation, a deficiency of electrons in covalent bonding, is a common feature in hydrogen-rich superconductors, but may not be limited to hydrides. Li *et al.*[7] have identified the common structural character of six-coordinated octahedral networks in P_2S, P_3S, P_5S, P_8S, and $P_{11}S$, and have investigated the bonding-unsaturation dependence of superconductivity in these compounds. Their study finds that the average bonding unsaturation of P-rich compounds is proportional to the predicted superconducting transition temperature. Pei *et al.*[8] have observed pressure-induced reemergence of superconductivity in two new clathrate-like, or caged, superconductors, BaIr$_2$Ge$_7$ and Ba$_3$Ir$_4$Ge$_{16}$. The findings of this research, combined with high-pressure synchrotron x-ray diffraction and Raman measurements, provide insights into the underlying mechanisms of pressure-induced superconductivity. Talantsev[9] has analyzed the Fermi velocity V_F of all newly discovered highly compressed near-room-temperature superconductors and has proposed a universal Fermi velocity relationship with the ratio of ground-state amplitude of the energy gap to the superconducting critical temperature.

According to this model, V_F in all near-room-temperature superconductors lies in the range (2.5–3.8) × 10^5 m/s, providing a guideline for future studies of high-T_c superconductors under extreme conditions.

Extraordinary breakthroughs usually occur beyond a comfortable frontier, and initial evidence and interpretations are necessarily weak. We believe scientific debates are healthy and helpful for accelerating the technical advances and panning out the true gems. Two papers by Jorg E. Hirsch, a strong critic of the pressure-induced near-room-temperature superconductors, are published in this Special Volume to include the alternative viewpoint. Hirsch and van der Marel[10] present clear evidence that the results for ac susceptibility published by Ranga Dias's group are not supported by the reported raw data and cannot be obtained from the raw data following generally accepted scientific procedures. This criticism has been followed by retraction of Dias's paper by *Nature*.[11] Hirsch and Marsiglio[12] have also analyzed the magnetization results from Mikhail Eremets's group[4] and have concluded against superconductivity in hydrides. There is clearly a strong difference in opinion here, and it is to be hoped that results regarding superconductivity in these materials will soon be made more robust by progress in experimental techniques.

Advances in high-pressure science are dictated by the technical capability of reaching extreme conditions and probing exotic properties through experiments or theoretical analyses. Among the most fundamental pressure-induced changes are those in crystal structure. Xu *et al.*[13] describe a leading synchrotron beamline (the PX^2 Program) at the Advanced Photon Source with state-of-the-art experimental capabilities for single-crystal structure determination under extreme conditions. A comprehensive description of the beamline capabilities and a case study of natural ilvaite are provided. Sui *et al.*[14] present a brief overview of theoretical models related to the mechanisms of void nucleation and growth under dynamic loading. These theoretical models have been extended from traditional ductile metals to newly developed metallic materials that have good performance and wide prospects for applications, such as nanocrystalline materials and high-entropy alloys. The compression rate can have a strong influence on structural evolution and phase transition behavior. Between static and dynamic compression, precise control of the compression rate provides us with a unique tool to understand the underlying mechanisms associated with the external strain and strain rate over a large range. Su *et al.*[15] report a novel bidirectional controllable device for static and variable compression rates utilizing three piezoelectric actuators and a time-resolved spectroscopy and imaging device. A maximum 48 TPa/s compression rate has been demonstrated with a 300 μm culet anvil.

The favorable physical and chemical properties discovered so far at high pressures are useless to practical materials science unless they can be preserved at ambient pressure. Learning from geoscience, where diamond inclusions are able to preserve the high pressure conditions of the deep Earth regions where the diamonds originally formed, Mao and Mao[16] propose a strategy to encapsulate desired materials in synthetic diamond capsules to preserve their favorable properties under high pressure for applications under ambient condition, thus overcoming the obstacles encountered in truly high-pressure materials science. On the geoscience front, Lin and Mao[17] have discovered a mechanism by which water is carried down via dense hydrous silica through the entire mantle to the core–mantle boundary, thus resolving the long-standing mystery of oxygen fugacity heterogeneity. Hirao *et al.*[18] have conducted extremely challenging measurements on the equations of state of iron and nickel, which are the major constituents of the Earth's metallic core, up to the core pressure of 368 GPa. They have found that both iron and nickel are less dense than previously thought, a discovery that demands some reconsideration of existing models of Earth's core composition and planetary evolution.

H. K. Mao is supported by the National Natural Science Foundation of China under Grant No. U1930401.

AUTHOR DECLARATIONS

Author Contributions

Ho-kwang Mao: Conceptualization (equal). **Bin Chen**: Conceptualization (equal). **Huiyang Gou**: Conceptualization (equal). **Kuo Li**: Conceptualization (equal). **Jin Liu**: Conceptualization (equal). **Lin Wang**: Conceptualization (equal). **Hong Xiao**: Conceptualization (equal). **Wenge Yang**: Conceptualization (equal).

DATA AVAILABILITY

Data sharing is not applicable to this article as no new data were created or analyzed in this editorial.

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