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Solids under coupled extreme conditions: Simultaneous exposure to pressure, temperature and ion beams

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Recent advances in the design of diamond anvil cells and techniques for reaching extremely high pressures and temperatures have been combined with irradiations using swift heavy ions. These relativistic ions provide a unique opportunity to access states of matter quite far from thermodynamic equilibrium [1]. Each projectile deposits exceptional amounts of kinetic energy (GeV) within an exceedingly short interaction time (sub-fs) into nanometer-sized volumes of a material, resulting in extremely high energy densities (up to tens of eV/atom). The coupling of extreme energy deposition with high pressures and high temperatures, realized by injecting the relativistic heavy ions through a mm-thick diamond anvil of the pressure cell, dramatically alters transformation pathways and can lead to the formation of new states of matter. This innovative experimental approach allows us to probe the behavior of materials under extreme conditions, to form and stabilize novel phases in a wide range of oxides (e.g., GeO2 and Gd2Zr2O7) [2], and to manipulate the physical and chemical properties of solids at the nanoscale (e.g., CO2). A further application is to investigate the effects of radioactive decay events in compressed and heated minerals of Earth's interior, such as fission-track formation under crustal conditions and phase transitions of damaged minerals (e.g., ZrSiO4) resulting from meteorite impact [3]. This presentation describes the state-of-the-art science in this field by presenting several examples of structural modifications induced by coupled extreme conditions, as well as outlines a vision for future research at FAIR.

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