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Analogue of asymptotic freedom in warm dense matter

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At sufficiently high energies, collisions of heavy ions melt protons and neutrons into sub-hadronic quarks and gluons. At still higher energies quarks and gluons are released from bonds to form quark-gluon plasma. In the process quark-gluon interactions become asymptotically weaker with increasing energy, a process called asymptotic freedom (AF). In warm dense matter (WDM) at pressures P and temperatures T the crossover from fluid condensed matter to WDM is analogous to AF. WDM with $0.1 < P < 20$ TPa (2×10^8 bar) and $T < 0.1$ keV with lifetimes between a few and a few 100 ns is achieved experimentally by dynamic compression. Such extreme states in dense atomic-like matter are achieved by hypervelocity impact driven by (i) H₂-gas dynamics in a two-stage gun, (ii) magnetic-flux compression in an electro-magnetic launcher, (iii) radiation pulses in proximity to underground nuclear explosions and (iv) optical pulses at giant lasers. WDM is a poor metal with minimum metallic conductivity (MMC), typical of fluid metals. P , V , E states, where V and E are specific volume and internal energy, respectively, are generated in dynamic compression by a supersonic matter wave. The Hugoniot equations relate P , V , E states achieved behind the wave front to their initial values ahead of the front and to supersonic velocity u_s of the wave front and material velocity, also known as particle velocity, u_p behind the front. Velocities u_s and u_p are determined experimentally and used to calculate P , V , E via the Hugoniot equations. For a single sharp rise in pressure in the front the matter wave is known as a shock wave. Shock-compression (Hugoniot) data of Al, Cu, Fe and Mo are plotted as $u_s(u_p)$ in Fig. 1. Data points in upper Right and lower Left corners are at 20 TPa and 0.4 TPa (4 Mbar), respectively. Data in Fig. 1 lie on the same straight line, independent of P , T and Z . At high shock P/T in Fig. 1 those metals are fluids with MMC of few 1000 S/cm. To determine if insulators behave similarly, shock-compression and optical-reflectivity experiments were measured on Gd₃Ga₅O₁₂ (GGG) in the range 0.4 to 2.4 TPa. Hugoniot data of fluid GGG measured below 0.3 TPa and above 0.9 TPa. GGG is less compressible than diamond above 0.17 TPa measured optical reflectivities indicate fluid GGG becomes a poor metal with MMC at $\sim$ TPa shock pressures, as do fluid metals Al, Cu, Fe and Mo and other materials. Below 0.3 TPa fluid GGG is virtually incompressible with strong metal-oxide directional bonds. Above $\sim$ 0.9 TPa fluid GGG is a much more compressible itinerant-electron fluid with MMC.

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