Quantum Magnetohydrodynamics: a Review

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The suitable density and temperature ranges where quantum effects are relevant for plasmas are reviewed. Typically such quantum plasmas are characterized by large densities and low temperatures, with a significant overlap of the wave packets of the charge carriers. In this case the wave nature of electrons, which have in general a much smaller mass than ions, becomes unavoidable deserving a quantum description. Examples arise in compact stars such as white dwarfs and neutron stars, in ultrasmall electronic devices and in intense laser-solid density plasma interaction experiments. Starting from quantum kinetic theory, we discuss the foundations and the need of quantum hydrodynamic models for the nonlinear treatment of quantum plasmas. In this context the quantum magnetohydrodynamic model is derived. The role of spin-statistics and relativistic effects is discussed. A detailed comparison between the kinetic theory and hydrodynamic models of the exchange interaction is provided in the case of quantum ion-acoustic waves. The validity conditions of quantum magnetohydrodynamics and the most recent developments are analyzed. In particular we shall discuss results involving magnetosonic solitons in fermionic quantum plasmas, the spin force and the macroscopic spin magnetization current, Hall magnetohydrodynamics with quantum effects in arbitrary degenerated spin ½ quantum plasmas in very dense environments, and the rigorous derivation of quantum exchange effects from quantum kinetic theory taking into account the exclusion principle.

References:

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Figure: density-temperature diagram for which the present modeling is applicable, in a logarithmic scale, where n0 is the equilibrium number density and T is the thermodynamic temperature. The left vertical line indicates the minimal number density for which correlation effects are negligible, also justifying the semiclassical approximation. The Fermi tempreture is TF .The right vertical line indicates the maximal number density to neglect relativistic effects.