Effect of Landau quantization for varying magnetic fields in degenerate electrons and its implications to astrophysics and quantum speed limit

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We investigate the two-dimensional motion of relativistic cold electrons in the presence of magnetic field. We know that such a system in a uniform magnetic field leads to the quantization of electron energies in Landau levels in the plane perpendicular to the direction of the field. We show that in the presence of 'strictly' spatially varying magnetic fields satisfying, however, no magnetic monopole condition, Landau orbitals change which has significant implications. We find that the degeneracy of Landau levels, which arises in the case of the constant magnetic field, lifts out when the field is variable and the energy levels of spin-up and spin-down electrons align in an interesting way depending on the nature of change of field [1]. Also the varying magnetic field splits Landau levels of electrons with zero angular momentum from the positive angular momentum, unlike the constant field which only can split the levels between positive and negative angular momenta. Exploring Landau quantization in non-uniform magnetic fields is a unique venture on its own and has interdisciplinary implications in the fields ranging from plasma physics to astrophysics to quantum information.

For example, this affects equation of state (EoS) of magnetized matter consisting of degenerate electrons. As the field decreases spatially faster, EoS becomes stiffer at a high density and softer at a low density [1], due to lesser number of allowed levels in the system, as shown in Fig. 1. The situation is opposite for spatially growing field.

We subsequently show that magnetized white dwarfs, consisting of Landau quantized degenerate electron gas [2], may exhibit a significant violation of the Chandrasekhar mass-limit [1,3]. Further, we show that a spatially growing magnetic field leads to an increase in quantum speed limit of electrons [4], which prompts for a faster evolution of quantum states and quantum information processing.

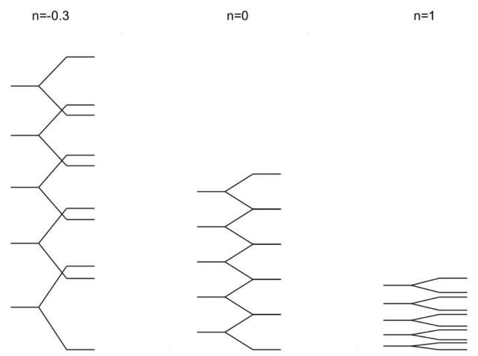

Figure 1: Comparison of schematic representation of the energy level splitting between the spatially decaying (n<0), uniform (n=0) and growing (n>0) magnetic field.

An analytical framework is developed. We also provide a plausible experimental design to supplement our theory.

References:

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