Contribution ID: **48**

Type: **Talk in a parallel session**

Broken energy degeneracy in non-uniform magnetic field: Faster quantum speed limit

Monday, 8 July 2024 17:20 (20 minutes)

When charged fermions gyrate within a uniform magnetic field, their energy undergoes quantization into discrete levels known as Landau levels, a phenomenon termed Landau quantization. This effect finds diverse applications, ranging from the quantum Hall effect and the de Haas Van Alphen effect to the formation of super-Chandrasekhar white dwarfs. In a uniform magnetic field, Landau levels exhibit degeneracy due to the overlap of spin-up fermions in lower energy levels with spin-down fermions in the adjacent higher energy levels.

Our investigation focuses on the two-dimensional motion of relativistic cold electrons amidst spatially varying magnetic fields. We observe that the degeneracy of Landau levels, that arises in constant magnetic fields, lifts out in the presence of variable fields, with the energy levels of spin-up and spin-down electrons aligning in intriguing ways depending on the field's nature of change. We propose an experimental setup for achieving non-uniform magnetic fields in laboratory settings.

Utilizing the spatially growing magnetic field, we aim to attain a higher quantum speed limit,the faster transition speed between the quantum states, for electrons. This advancement holds significant promise for accelerating quantum information processing, particularly in the realm of quantum computing. Furthermore, we determine the critical magnetic field that bridges the gap between non-relativistic and relativistic regimes, employing the Bremermann-Bekenstein bound to constrain the maximal rate of information production.

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Session Classification: Strong electromagnetic and gravitational field physics: From laboratories to early Universe

Track Classification: Strong Fields (SF): Strong electromagnetic and gravitational field physics: From laboratories to early Universe