QC2024 – Rotation, magnetic fields and superconductivity

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We review exotic effects of extreme rotation (~ 10^{22} Hz) and strong magnetic fields (~ 10^{20} T) in the Standard Model of fundamental particle interactions, making Quantum Connections to time-crystalline states that may be realized in the context of condensed matter physics.

The lectures aim to focus on provocative questions that are the subject of ongoing research on strong (spin) polarization effects emerging in response to background fields or rotation: (i) Can a (closed) system possess a negative moment of inertia? (ii) Can the vacuum become an electromagnetic superconductor? (iii) If yes, what are the consequences in both cases? Here are some examples:

- The phenomenon of negative moment of inertia can surprisingly arise in hot (~ 10^{12} K) rapidly spinning quark-gluon plasma described by the Quantum Chromodynamics sector of the Standard model. This type of matter filled once the primordial Universe and is now routinely created in non-central collisions of relativistic heavy ions. Supported by recent first-principle numerical simulations, the negative moment of inertia results from au unusual response of a medium of strongly interacting spinful particles — in this case, gluons—to global rotation (a relativistic version of the Einstein-de-Haas and Barnett effects, both discovered experimentally in 1915). Strikingly, such states could leave an experimentally measurable imprint on spin polarization of particles produced in non-central relativistic heavy-ion collisions.
  - (review) *Polarization and Vorticity in Quark–Gluon Plasma*, 10.1146/annurev-nucl-021920-095245
  - (research) *Negative moment of inertia and rotational instability* … , 10.1016/j.physletb.2024.138604

- Superconductivity of the vacuum appears in the Electroweak sector of the Standard Model. This unusual effect is catalyzed by a long-disputed instability of the vacuum emerging in a strong magnetic field, predicted more than 30 years ago as an extreme relativistic version of the Zeeman effect, and confirmed only recently in first-principle numerical simulations. The vacuum (= a state devoid of any matter) becomes a disordered liquid-like solid made of vortices parallel to the magnetic field. This vacuum phase appears to be an electromagnetic superconductor (!) and, at the same time, a superfluid. The relevant strong-field conditions may exist even today near highly magnetized black holes, motivating additional curious inquiries on its observability.
  - (research) *Phase Structure of Electroweak Vacuum* …, 10.1103/PhysRevLett.130.111802
  - (video) https://www.youtube.com/watch?v=-TCZcLZWIBk

- We also discuss how the negative moment of inertia and ordinary superconductivity can interplay with each other to support time-crystalline states in condensed matter setup (to appear).