CONDENSED MATTER SCIENCES SEMINAR

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Boston University

Host

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Title

Moving Born–Oppenheimer Approximation: Emergent Pseudo-forces and Quantum Geometry

Friday, January 16th, 2026

1st Floor – B101

15:00-16:00

Abstract

Many complex systems exhibit a strong separation of timescales, which greatly simplifies their theoretical description. A familiar example is a bucket of water: when the bucket moves slowly, the water surface remains nearly horizontal and follows an instantaneous equilibrium. This intuition underlies the Born–Oppenheimer approximation (BOA), which is widely used in quantum chemistry, condensed-matter physics, and other areas where heavy and light degrees of freedom evolve on different timescales. However, as the motion of the slow degrees of freedom becomes faster, the BOA breaks down. Pseudo-forces emerge and drive the system into a new, "moving" equilibrium. In many realistic settings, the fast degrees of freedom are quantum mechanical while the slow ones are effectively classical, yet the system as a whole exhibits synchronized dynamics.

In this talk, I will first show that the standard BOA violates several fundamental physical principles. In particular, it neglects the inertia contributed by the fast degrees of freedom, leading to an effective violation of the equivalence principle. It also conflicts with the uncertainty principle and breaks charge neutrality, since moving nuclei are not accompanied by the corresponding electronic motion within the BOA.

I will then introduce a new framework—the Moving Born–Oppenheimer Approximation (MBOA)—in which the momentum of the slow degrees of freedom is coupled to that of the fast ones through the adiabatic gauge potential, a central object in quantum information geometry, which also emerged in defining chaos. This coupling generates pseudo-forces that can have nonperturbative effects on both sectors, producing a self-consistent, synchronized motion. As a result, the fast degrees of freedom can become squeezed and entangled, and more exotic collective states can emerge.

Finally, I will argue that the MBOA admits a natural extension to equilibrium systems. In this formulation, the velocity of the slow degrees of freedom—and even the notion of motion itself—emerges from thermodynamics, with velocity playing the role of a thermodynamic force conjugate to momentum in the moving frame.