Emergence in the Fractional Quantum Hall Effect

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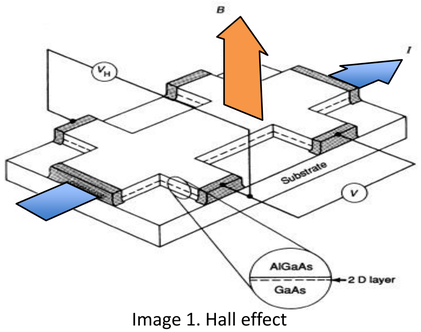


Image 1. Hall effect

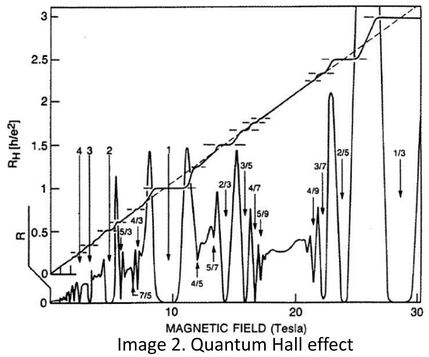


Image 2. Quantum Hall effect

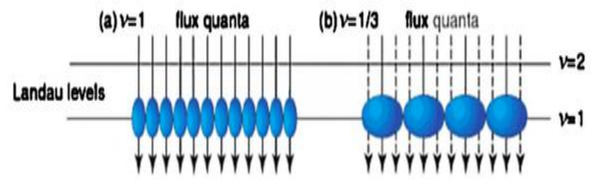


Image 3. Flux Quanta

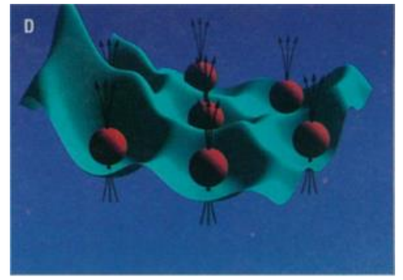


Image 4. Wave functions and flux quanta

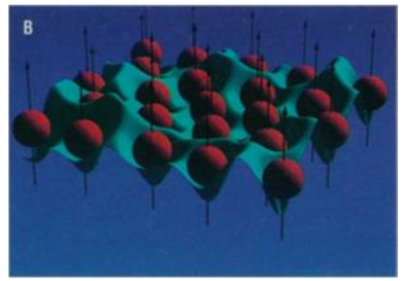


Image 5. Wave functions and flux quanta

Abstract

The experimental discovery of the fractional quantum hall effect (FQHE) in 1980 was followed by attempts to explain it in terms of the emergence of a novel type of quantum liquid. This project seeks to articulate a notion of emergence that is compatible with the observed phenomena associated with the FQHE. Doing so is important for at least two reasons. First, notions of emergence have been used by physicists for quite some time to describe other types of condensed matter systems such as superconductors, superfluids, and Bose-Einstein condensates; however only fairly recently have philosophers begun to take notice: traditionally, notions of emergence in philosophy have been restricted to the philosophy of mind and general metaphysics. Second, for some authors, a notion of emergence must include an account of a mechanism by means of which emergent behavior is realized; but this is problematic in the case of the FQHE due to there being at least four alternative explanations that appeal to ontologically distinct mechanisms, none of which is more privileged than the others.

The goals of this project are to distinguish the fundamental features of the FQHE that make it distinct from other condensed matter systems that exhibit emergent behavior, to juxtapose accounts of emergence in the philosophy of mind with accounts of emergence in physics, and finally to provide an alternative, non-mechanism-centric, account of emergence that is applicable to the FQHE.

Quantum Hall Effect

Classical Hall Effect:

- Current though conductor
- Perpendicular magnetic field
- Accumulation of electric = magnetic force
- Trajectory of current becomes stable

Quantum Hall Effect:

Hall effect under conditions of

- Low Temperature (~0.02K)
- Large magnetic field (~30T)

Results in quantized values of Hall resistance into Landau levels.
Values of magnetic field correspond to filling factor (ratio of electrons to magnetic flux quanta), which can either be an integer (IQHE) or fraction (FQHE).

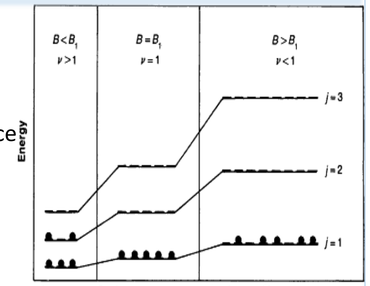
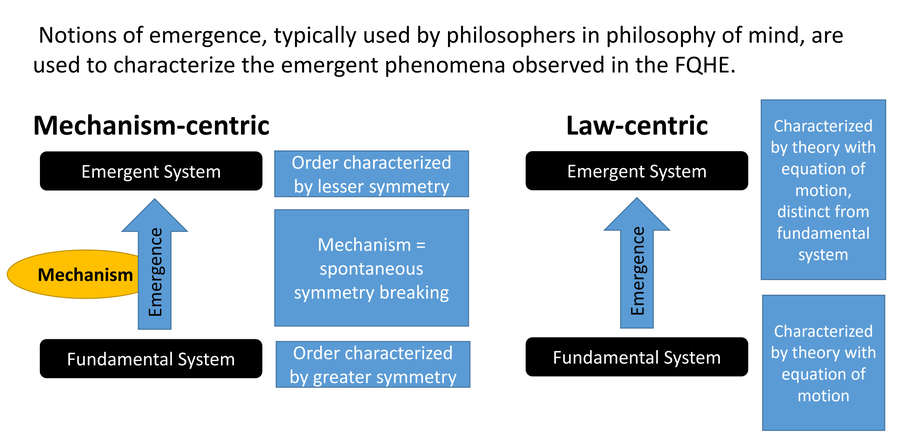


Image 6. Landau levels in a five-electron system

Emergence

Notions of emergence, typically used by philosophers in philosophy of mind, are used to characterize the emergent phenomena observed in the FQHE.



Distinct categories for notions of emergence allow for more rigorous analysis of notions of emergence in condensed matter physics, which is itself distinct from reduction.

	Microphysicalism	*Derivability*	*Novelty*
Reduction	✓	✓	×
Mechanism-centric	✓	×	✓
Law-centric	✓	×	✓

Articulating emergence is important so that notions of emergence do not become trivial when dealing with what appears to be emergent phenomena in condensed matter physics.

Works Cited

[1], [2], [4], [5] Eisenstein, J. and H. Stormer. (1990). "The Fractional Quantum Hall Effect," *Science.*
[3] Ezawa, Zyun. (2008). *Quantum Hall Effects*. World Scientific.

Observation

	Microphysical mechanism		*High-level mechanism*
	R = 0	**Plateaus in RH**	
Laughlin ground state	A many-body Coulomb effect of electrons.	Quasiparticle–impurity interactions.	Localization, instantiated by electron–impurity interactions.
Composite fermion	A one-body effect of composite fermions.	Composite fermion–impurity interactions.	Localization, instantiated by composite fermion–impurity interactions.
Composite boson	A many-body effect of composite bosons.	Vortex–impurity inter-actions.	Spontaneous symmetry breaking, instantiated by composite bosons.
Topological order	A many-body entangled effect of electrons.	Quasiparticle–impurity interactions.	Long-range entanglement, instantiated by electrons.

Table 1. Alternative mechanistic accounts of the FQHE, including new framework of high-level mechanism.

Where We Are and Where to Go

Examination of the current dominant accounts of the FQHE bring us to the conclusion that:

- Even with introducing a high-level mechanism—similar to a law-centric mechanism—neither account is more privileged than the other.
- As notions of emergence become more common place in condensed matter physics, emergence in philosophy of mind and philosophy of physics must be juxtaposed to continue the discussion of whether introducing emergence is trivial or non-trivial.