Phys525:
Quantum Condensed Matter Physics:
emergent phenomena in CMP

episode One: Introduction and Why Emergent phenomena ?

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- Why emergent phenomena/symmetries?

Interacting quantum many-body systems:
"emergent phenomena"

More Is Different

Broken symmetry and the nature of the hierarchical structure of science.

P. W. Anderson

The reductionist hypothesis may still be a topic for controversy among philosophers, but among the great majority of active scientists I think it is accepted

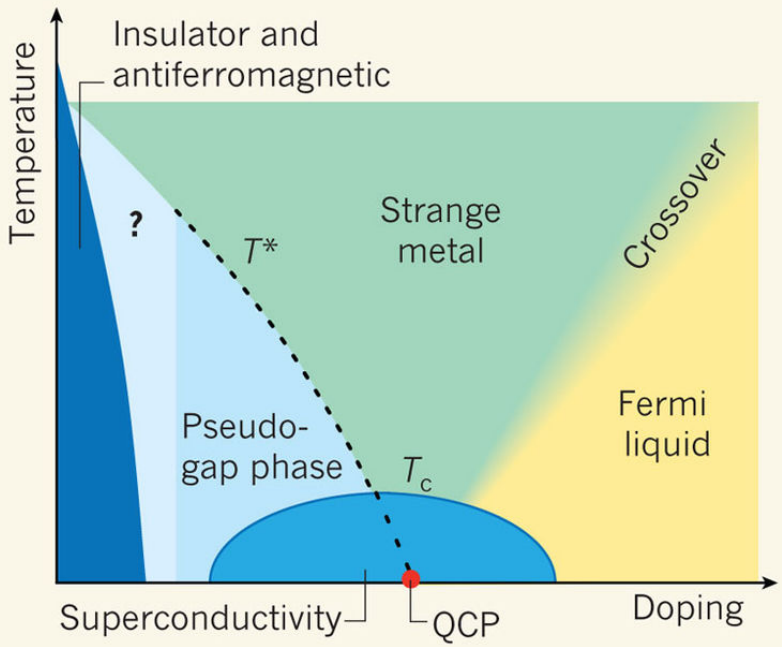
planation of phenomena in terms of known fundamental laws. As always, distinctions of this kind are not unambiguous, but they are clear in most cases. Solid state physics, plasma physics, and perhaps

less relevance they seem to have to the very real problems of the rest of science, much less to those of society.

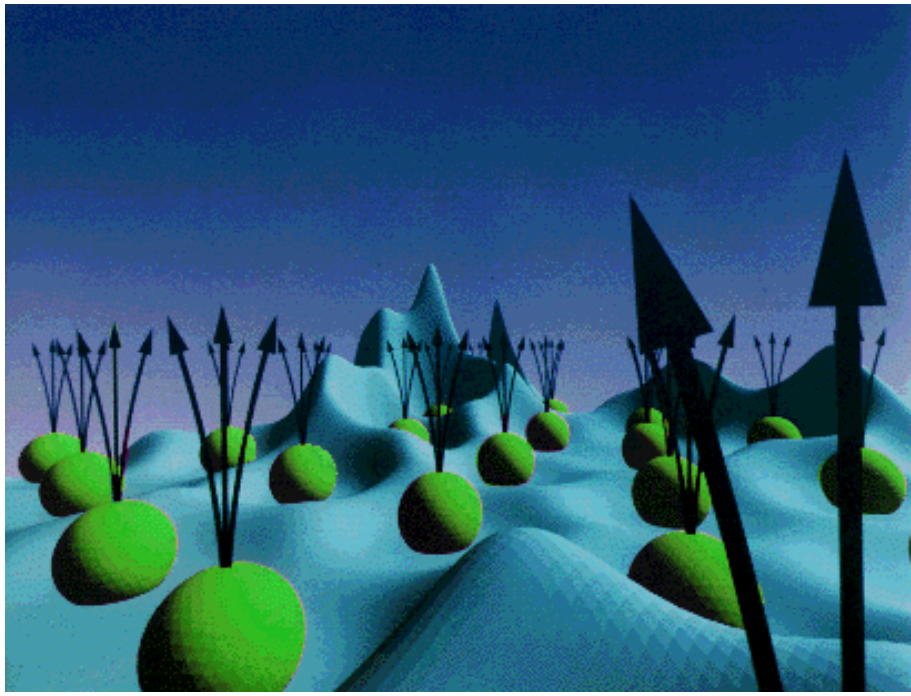
The constructionist hypothesis breaks down when confronted with the twin difficulties of scale and complexity. The behavior of large and complex aggregates of elementary particles, it turns out, is not to be understood in terms of a simple extrapolation of the properties of a few particles. Instead, at each level of complexity entirely new properties appear, and the understanding of the new behaviors requires research which I think is as fundamental in its nature as any other. That is, it seems to me that one may array the sciences roughly linearly in a hierarchy, according to the idea: The elementary entities of science X obey the laws of science Y.

Large scale quantum phenomena can't be understood as a simple extrapolation of microscopic individual particles. Strong interactions lead more exotic phenomena.

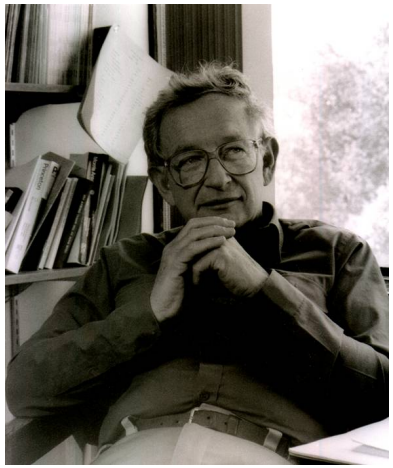
Emergent Quantum Phenomena: More is different



Superconductor (HTcS)
1) electrons can condense and super-flow!
2) strongly interacting electron can super-conduct at high T.



Fractional Quantum Hall (FQH)
Laughlin state with 1/3 electron per flux in B-field
Quasi- particles carrying 1/3 of electron charges.



"emergent phenomena" and why they are surprising?

More is different!

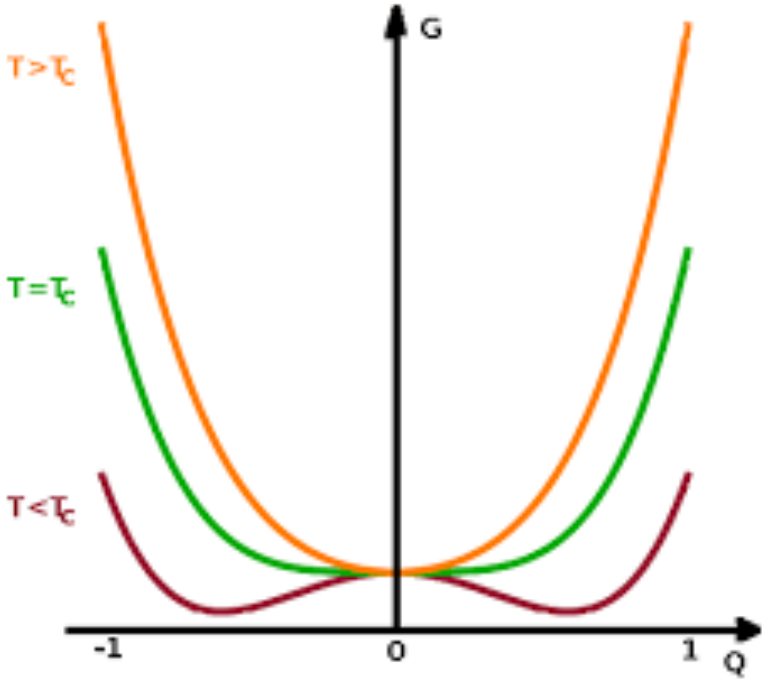
A) Quantum matter can break the symmetries of the microscopic interactions (Superconductor/superfluid, ferromagnetic-anti-ferromagnetic etc).

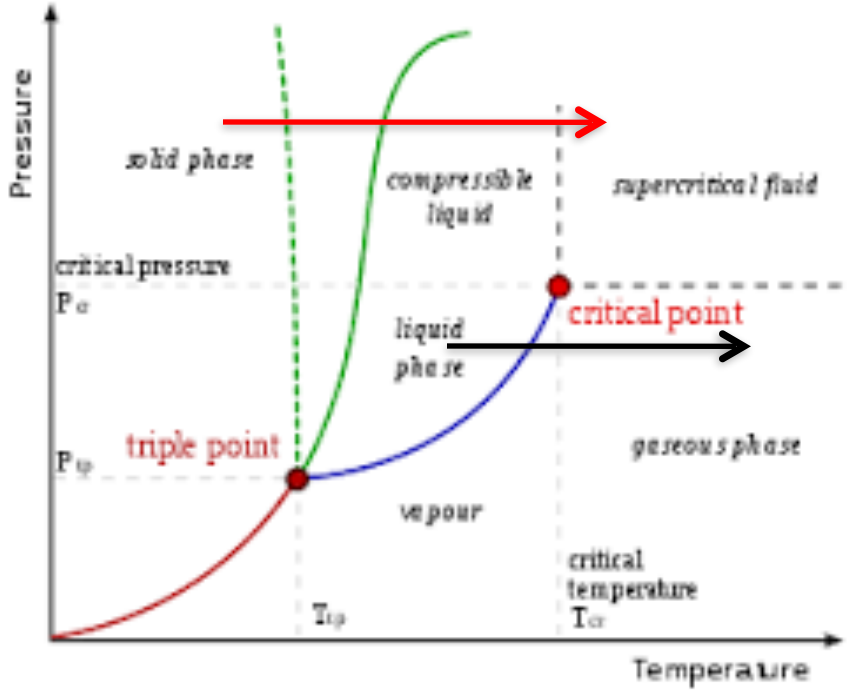
B) Strong interactions +high "degeneracy" due to either quantum or classical configurations; leading to fractionalization/non-local " topological order" (i.e.FQHs, spin liquids etc); an exciting frontier.

[Both A) And B) are separated from ordinary matter by QCPs.]

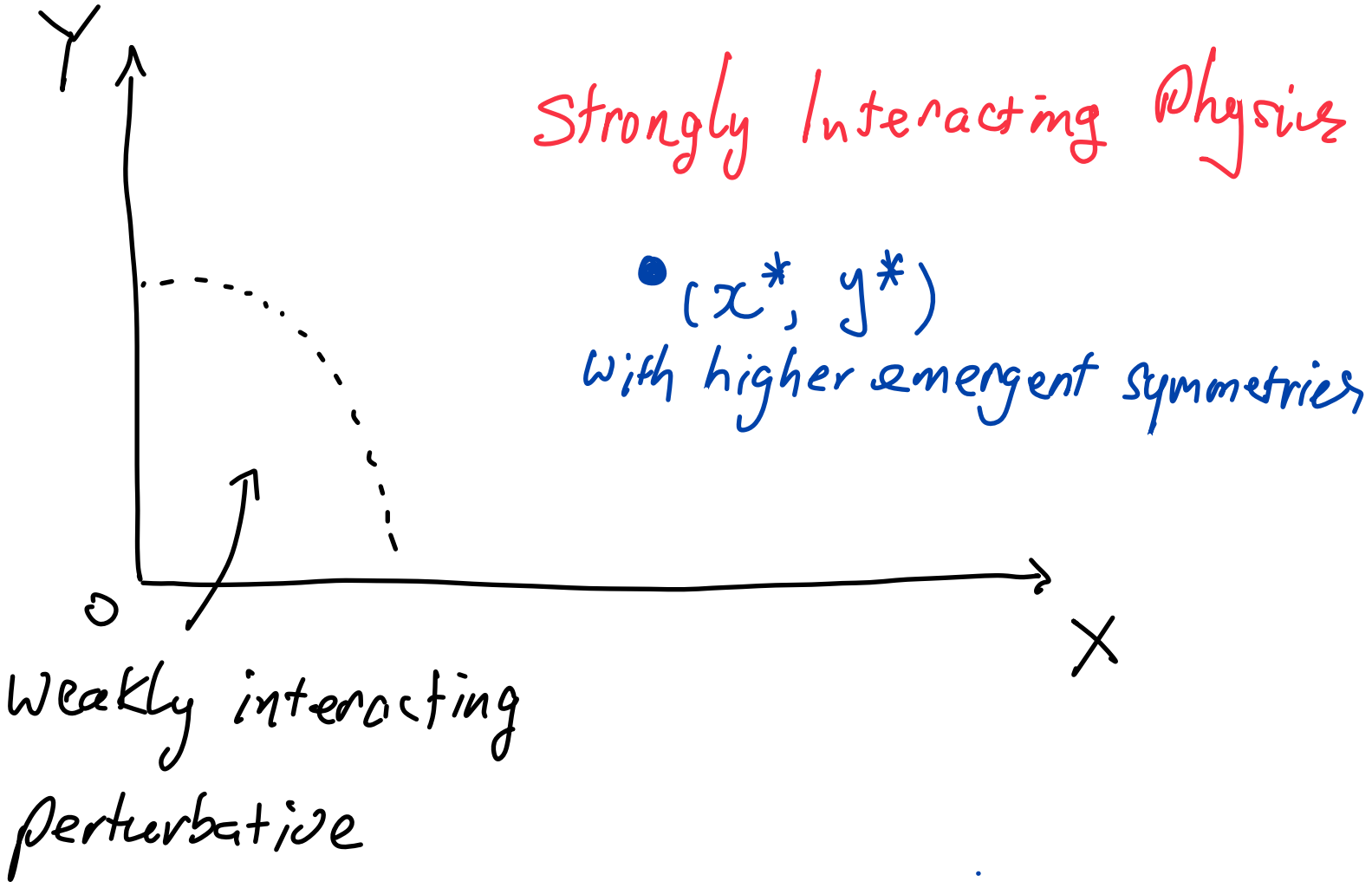
C) (Strong) interactions in quantum crystals can further lead to emergent symmetries both internal and/or space-time symmetries as large scale quantum phenomena, often very surprising from fundamental physics points of view.

Landau paradigm for order-disorder Phase Transitions





There have to be phase transitions if ordering occurs.


Y
X
O
Strongly Interacting Physics
(x^*, y^*)
with higher emergent symmetries
Weakly interacting
perturbative

Physics525 course information

General References:

1) Quantum Phase Transitions, Subir Sachdev (Cambridge University Press, 2nd ed., 2011)
2) An introduction to Quantum field theory, Michael Peskin and Daniel Schroeder (CRC press, Taylor and Francis, 1995)

more special references will be provided after Part I.

Ideally,Phys516 or Phys526 set the starting points for our discussions.