(New) Phases of Matter
Discussion session, Strings 2021

Nathan Seiberg

IAS

No references

Why should string theorists care about this topic?

"Condensed Matter Physics is not fundamental physics."

"Quantum Field Theory is fully understood."

I strongly disagree.

Deep and productive cross-fertilization between Condensed Matter Physics and High Energy Physics/String theory

Almost every idea in HEP/ST either had its roots in CMP or had implications in CMP.

I expect developments in CMP to inspire more developments in HEP/ST.

Separation of scales – reductionism, the renormalization group

- A theory in the UV (e.g., lattice theory) flows to another theory in the IR.

- The low-energy physics is described by a continuum QFT.

  - Effective, universal description – independent of most of the short distance details.

- Continuum QFT classifies and organizes the possible phases and the transitions between them.

- Interesting new phases teach us about QFT.

UV theory at short distances

IR theory at long distances

Counterexamples – UV/IR mixing

UV/IR mixing – no separation of scales – long-distance/low-energy phenomena reflect high-energy physics.

- Common in gravity:

    – High energy in a small volume leads to a large black hole, hiding the short-distance physics

    – Dualities relate small ↔ large

    – Many questions and confusions in quantum gravity circle around this issue

- String theory with vanishing Newton constant is a non-gravitational theory. Typically, it is a QFT. But certain peculiar examples exhibit UV/IR mixing…

Counterexamples – UV/IR mixing

- Examples based on limits of string theory
  - Little string theory
    - No local operators
    - T-duality
  - Field theory on a non-commutative space
    - dipole with high momentum is large in space along another direction
    - comparing with the same theory on a commutative space, fewer UV divergences and instead new IR divergences
- Exotic lattice models (including models of fractons)
  - Subsystem symmetry

Subsystem symmetries (Shao's talk)

Different symmetry elements for different submanifolds, e.g., different planes.

- Operators and states are in a representation of the subsystem symmetry.

  - Large ground state degeneracy, which can depend on the number of lattice points

  - Observables vary at the lattice scale, and hence they are discontinuous in the continuum limit

- UV/IR mixing

A continuum QFT description of the long-distance behavior of these models must involve discontinuous fields.

Questions and challenges

- What is QFT?
  - Many formulations (starting with continuum Lagrangians, lattice, bootstrap, integrable theories, string constructions, etc.), but none is perfect and none covers all cases.
  - New formulations?
    - Deeper understanding
    - New theories
    - New methods for calculations
- Generalized QFT?
  - UV/IR mixing (little string theory, field theory on non-commutative spaces, theories with exotic global symmetries)
  - Others?