CONDENSED MATTER THEORY

As with the high energy strand, our main tool is **field theory**:

High energy = reductionist
= smaller and smaller = higher and higher energy

Condensed matter = anti-reductionist = how do pieces act together
and what new physics can **emerge** when this happens

Extremely intellectually challenging and mathematically sophisticated:
We are not interested in the “easy” asymptotically free regime at high energy (i.e., accelerator physics), but rather the complex highly interacting physics of low energy (i.e., everything else).

Emergent phenomena that you would never guess can arise from the “microscopics.”
Ex: can a particle with 1/3 of an electron charge can arise from a many electron quantum soup? (it does!)

Cond-Mat on offer this term:

Advanced Quantum Theory* and/or Quantum Field Theory* =

Quantum Field Theory, Feynman Path Integrals (including finite temperature!), Quantum Many Body Physics (leads into Renormalization Group HT, Quantum Matter, TT)

Kinetic Theory = Boltzmann transport, collisions, hydrodynamics, Non-hbar for this course. (leads to Nonequilibrium Stat Mech, HT)

Topological Quantum Theory = (the 2016 Nobel Prize!)

Topological quantum field theory, topological quantum matter, topological quantum information and quantum computing. Field arose from ideas in quantum gravity, topology, and condensed matter physics. (leads to Quantum Computing HT, Quantum Matter TT) [I teach this!]

Soft Matter (starts week 5 - HT)= Phase ordering, Liquid Crystals and topological defects, Introduction to active matter, Polymers:statics and dynamics, Self-assembly. (Non hbar)

What is condensed matter?

- Condensed Matter ≈ The study of complex systems with many components (many parts, many atoms, many…).
  - Often meaning "substances" or the physics of "stuff"

    i.e., the world around you!

- Mathematically Rich and Beautiful

- Intellectually Tremendously Challenging

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(Received 31 August 1964)

In a recent note[1] it was shown that the Goldstone theorem,[2] that Lorentz-covariant field theories in which spontaneous breakdown of symmetry under an internal Lie group occurs contain zero-mass particles, fails if and only if the conserved currents associated with the internal group are coupled to gauge fields. The purpose of the present note is to report that, as a consequence of this coupling, the spin-one quanta of some of the gauge fields acquire mass; the longitudinal degrees of freedom of these particles (which would be absent if their mass were zero) go over into the Goldstone bosons when the coupling tends to zero. This phenomenon is just the relativistic analog of the plasmon phenomenon to which Anderson[3] has drawn attention: that the scalar zero-mass excitations of a superconducting neutral Fermi gas become longitudinal plasmon modes of finite mass when the gas is charged.

about the "vacuum" solution $\varphi_1(x) = 0$, $\varphi_2(x) = \varphi_0$:

$$\partial^\mu\{\partial_\mu(\Delta\varphi_1) - e\varphi_0 A_\mu\} = 0, \tag{2a}$$

$$\{\partial^2 - 4\varphi_0^2 V''(\varphi_0^2)\}(\Delta\varphi_2) = 0, \tag{2b}$$

$$\partial_\nu F^{\mu\nu} = e\varphi_0\{\partial^\mu(\Delta\varphi_1) - e\varphi_0 A^\mu\}. \tag{2c}$$

Equation (2b) describes waves whose quanta have (bare) mass $2\varphi_0\{V''(\varphi_0^2)\}^{1/2}$; Eqs. (2a) and (2c) may be transformed, by the introduction of new variables

$$B_\mu = A_\mu - (e\varphi_0)^{-1}\partial_\mu(\Delta\varphi_1),$$
$$G_{\mu\nu} = \partial_\mu B_\nu - \partial_\nu B_\mu = F_{\mu\nu}, \tag{3}$$

into the form

$$\partial_\mu B^\mu = 0, \quad \partial_\nu G^{\mu\nu} + e^2\varphi_0^2 B^\mu = 0. \tag{4}$$

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- Largest subfield of physics
  - 1/3 of all physics as measured by number of practitioners

- Extremely Broad and Diverse field

Example: Meeting of American Physical Society Condensed Matter (over 10,000 physicists attend…)

First day of the meeting at 8am lectures on the topics of…

- Superconductors,
- Superfluids,
- Glasses,
- Polymers,
- Microfluidics
- Crystal Growth Kinetics
- Spintronics
- Phase Transitions
- Quantum Criticality
- Bose Condensates
- Ultra High Pressure
- Ultra Low Temperature
- Ultra Fast Physics
- Topological Matter
- Quantum Computation
- Quantum Algorithms
- Ferromagnetism
- Anti Ferromagnetism
- Heavy Fermions
- Multiferroics
- Liquid Crystals
- Graphene
- Interfaces
- Heterostructures
- Fractionalized Charges
- Beyond Bosons and Fermions
- Quantized Hall Effects….
- Phase Transitions

… Plus 40 other topics. .. And this all at 8am the first day.

At 11am there are 65 completely different topics being discussed!

Strong Overlaps Between Condensed Matter and....

- Chemistry
- Material Science
- Biology
- Atomic Physics
- High Energy Physics (FIELD THEORIES!!!)
- Nanoscience
- Quantum Sciences
- And increasingly... String Theory, Black Holes (AdS/CFT)

Condensed Matter is good for your career:

- More job opportunities in condensed matter
  - Academic department of math, physics, biology, chemistry, materials, engineering.
  - National Labs
  - Industry!!!

  (Condensed matter enables technological revolutions!)

- LOTS of experimental data to study
  - Experiments are quick and cheap

- Explain the world around you!