Introduction to the course

This course has two main goals:

> Goals
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> 1) To understand the interaction among the constituents of matter and the novel phases which they produce
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> 2) To establish a common language that is capable of explaining a broad range of phenomena in condensed matter and beyond

The interaction among electrons may lead to ferromagnetism. The electron-ion interactions may lead to superconductivity. And so on. The most striking phenomena in condensed matter occur due to the interactions among its basic constituents.

In this course we will go over a large number of such problems. But during all our trajectory, our main focus will be on establishing a common language (ie, a way of thinking) You may eventually forget the specific calculations, but the language will stay with you forever (unless you smoke crack. then you will likely forget that too). Some of the concepts you will learn include

- Emergent properties and complexity
- Broken symmetries
- Excitations
- Second quantization

I will now try to explain some of these in detail.

Emergent phenomena

In CMP we usually know the laws of physics governing our system. what we want is to be able to extract meaningful information from these laws. For instance, a solid is made of protons and electrons interacting via coulomb forces. Thus the Hamiltonian of a solid will be

$$H = \sum_i \frac{p_i^2}{2m_i} + \frac{1}{2}\sum_{i\neq j} \frac{q_i q_j}{|r_i - r_j|} \qquad (1)$$

we can also complicate it further and add spin effects, relativistic corrections and so on. But the point is that writting down the Hamiltonian (the "law") is usually the easy part. The real question is what to do with it. Superconductivity, for instance, should somehow be contained in this Hamiltonian. But it is not at all obvious how to make that link.

The reductionist view is therefore wrong: knowing the basic microscopic interactions tells you nothing about macroscopic properties. This would be the same as saying that to understand biology all you need is to know the laws of chemistry. That is not true. Even though deep down a cell is just a bunch of chemical reactions, the enormous number of such reactions leads to completely new phenomena (life) which cannot be predicted by analyzing the individual reactions.

We say that life, or superconductivity, are emergent phenomena. what this means is that the properties of the whole cannot be predicted from an analysis of the individual parts. We are talking here about collective behavior.