Introductory discussion

Phys 502 - 2019

LECTURE 1

There are some important difficult questions:

1. Why atoms would condense?
2. What happens to the elementary particle when they are inside a digital lattice?
3. What kind of new excitations are possible?
4. Are there any kind of new defects in the digital space?
5. Why Metalic Fermi surface stable?

Hint: The modern notion is that physics of electrons in solids is not very different from the low-energy regime in particle physics

read. G. Volovik, "The universe in He drop" Oxford U. press.

Symmetries

- Systems desribed by H or $\mathcal{L}$
- Symmetry is a transformation which leaves H invariant

e.g. $r \to -r$, plane reflections
$t \to -t$ in non magnets

Landau idea: a specific new phase must break a certain symmetry.

e.g. liquid → solid
PM → FM or AFM

FM breaks spin rotation
time reversal

AFM in addition breaks
translational symmetry
between 2 sublattices

The pattern of symmetry is characterized by the "order parameter"

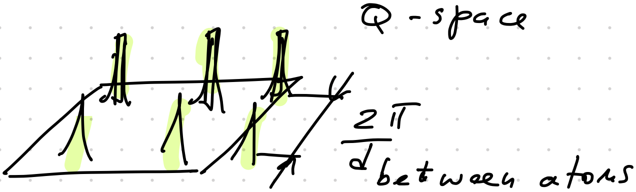
Order parameter is some physical quantity which transforms differently under some symm. operation from a Hamiltonian. In simple words it is something which is $\langle OP \rangle \neq 0$ in a new phase.

e.g. FM: $\langle M \rangle \rightarrow -\langle M \rangle$ if $t \to -t$

but $H \underset{t \to -t}{\rightarrow} H$

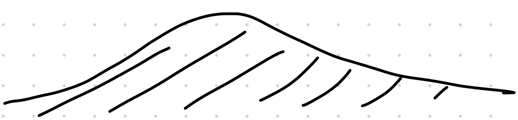
condensed xtal: OP is the Fourier transformed atomic density

Q-space



has sharp peaks

but nothing like this for liquids



e.g. superfluid
akin to superconductors but charge-neutral
characterized by a COMPLEX order parameter
↑ as in MATH!

which is A PHASE OF THE GLOBAL WAVE. function

Superfluid breaks this OP which corresponds to the particle number conservation
more on that in Lecture 2 on Landau-Ginsburg theory.

Is there anything beyond symmetry?

Welcome to the 21st century!

e.g. FQHE no symmetry is broken.

e.g. Band Metal ⟷ Band Insulator
both have the same symmetry!

or e.g. in strongly correlated materials
metal-to-insulator transition

We need a new idea which is not connected to the OP broken phase.

Here is a very simplified view.

You will learn soon that the difference

- in insulator all bands are filled and separated by a large gap from the empty bands (states)

- in metals at least one band is partially filled

$\Downarrow$

at least **1** Fermi surface

So we have a topological invariant

$\Rightarrow$ the number of Fermi surface sheets

This number is unaffected by the smooth deformation of the F.S.

Otherwise if this number changes the system undergoes a quantum phase transition (LIFSHITZ transition)

In short, many gaped materials may have non-trivial topological properties characterized by a topological order parameter

e.g.
- QHEs
- Topological insulators
- Weyl semimetals (no gap here!)
- superconductors

↓ in SC no spontaneous symmetry breaking!

but the ground state degeneracy depends on the topology

So the topological OP will have to be a measure of topology and entropy.

The end.