Quantum Materials, report on online material

Guillermo Abad

11 February, 2024

Theory videos, general report:

In general, I think the contents of the videos are very interesting, and they treat lots of amazing subjects, relating super interesting and hard topics in a single theme, personally, I've loved the most the time I've spent learning about the Berry connection and curvature, and its geometric origin with the adiabatic approximation... Having said this, I think the videos are summarized a lot, we see these amazing subjects very quickly and briefly, sometimes without a very clear connection between subjects. I would have loved more in-depth and slow explanations of the more complex subjects.

In the videos, the things I believe could have been improved mostly, are the following:

- **Context and big picture image:** Since these are "summaries", of the full classes, I sometimes felt lost, and didn't understood why we were doing something. I could follow all the computations, but I didn't know why we were doing them (With the notes, this improves).
- **Knowledge assumption:** The videos assumed, we knew concrete things, that we hadn't actually seen beforehand, luckily we can stop the video and search elsewhere, which I've had to do lots of times, but on most occasions enjoying it (I guess this would also improve with notes).
- **Brief mentions/explanations:** There are lots of very brief explanations, to which I would have loved to hear more complete ones, to understand or remind myself about such hard topics, like the origin of the Berry/geometric phase that can be seen from the Adiabatic approximation, the intuition for Brillouin zone periodicity from the Bloch theorem, or the relation of the Berry curvature with the gap and the virtual exchanges, etc.. (again, maybe notes would help here).

Now I'll state some concrete things in each video that left me with doubts, which I've had to search and understand by myself, and that might have complicated the online assignments:

02 Kramer theory:

- Why did we want to prove Kramer theorem? We don't use it afterwards, no? I guess for the time-reversal symmetry breaking, but this wasn't explained during any future videos, so I've missed the big picture.

03 Gauge invariance and Berry phase:

- The adiabatic theorem is mentioned real quick, but most people I think might have not ever seen it before.
- An explanation of why are we seeing Gauge invariances at all, maybe would help? I guess everything physical needs to be Gauge invariant, and we just wanna see the consequences of that here, but for people who haven't done particle courses, I think, just start working with Gauges, might be very shocking.

04 Topological properties of Bloch states:

- The mention of how a crystal solution, the Bloch states, relates to the Brillouin zone, maybe was too quick, and some intuition about it would have been much appreciated. I ended up searching for it myself.
- Maybe a quick explanation of the Gauge manifold as the quantum field of photons and electromagnetism, explaining that it behaves like space-time manifolds in General relativity where you can go from linear integrals of the connections, into enclosed surfaces integrals of the curvature, would have been insightful.

- During the perturbation theory part, you quickly mention, that we have virtual photon exchanges and that these are related to the Berry curvature, and they both depend on the gap.. Maybe a more in-depth comment here would be appreciated. I guess the reason the Berry curvature depends on the gap, is due to some resonance in the virtual exchanges as the two levels become close, but I don't fully get its intuition.

05 Transport and Berry curvature:

- Respect how the Berry curvature gives rise to an extra component in the velocity, apart from the dispersion one given by the bounds. I think some of us didn't know about this first component mentioned.
- Why do we need the broken time-reversal symmetry, for getting the Chern number expression of the hall conductivity? We just saw Kramer's theorem, not how broken symmetries affect the system topology.
- Why is the Chern number an integer, it is a closed integral of phases, which needs to be quantized I guess? Also, an example of topological stability, due to the Chern number, would have been much appreciated!

06 Haldane Model:

- Why does the mass term of the Hamiltonian break the time-reversal symmetry? I guess due to the σ_z, but until I saw it in the tutorials I didn't catch this, and I still think I'm missing some intuition about it.

07 The Kane & Mele model:

- The last two videos complemented very well with the tutorials, and helped to unite everything nice job!

Google colab, general report:

As just said, the tutorials, complemented and were complemented very well together with the last two theory videos, and I'm pretty positive that with some more internet browsing, I'll be able to understand everything and do a good assignment this week.

To finish, some more concrete things about some of the tutorial videos and colab links:

Handson tutorial #1:

- Duplicated video in the web page, appears as "Tutorial 1#: introduction" and "Handson tutorial #1".
- I didn't completely get, why do we have to distinguish a's and b's in graphene, passing a σ_x at 'qsymm.groups.PointGroupElement' unitaries definition.

Handson tutorial #3 (Assigment):

- This tutorial link doesn't seem to work, the provided link takes me to the 2nd tutorial. But at least it can be read from the long Colab containing everything (the 4 colabs together).