THEORETICAL PHYSICS RESEARCH PROJECT FOR M2

Anderson localization with more ways to propagate in one direction than in the other direction

Denis Basko & Robert Whitney
Laboratoire de Physique et Modélisation des Milieux Condensés (LPMMC), Grenoble
Contact: robert.whitney@lpmmc.cnrs.fr, denis.basko@lpmmc.cnrs.fr

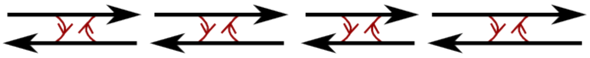
Quantum mechanics is a wave theory, for which interference effects are crucial. This is a principal difference from classical mechanics. One of the most surprising effects of interference is that it completely blocks the flow of waves in a one-dimensional geometry, as soon as there is even an infinitesimally small reflection probability per unit length. Hence, we say that quantum particles are always localized in one-dimension (because the reflection probability is never strictly zero in any real system). This effect is known as ***Anderson localization*** [1], and contributed to Anderson winning the Nobel prize in 1977.

This is very different from classical mechanics for which a small reflection probability just gives rise to diffusive motion of the particles. The difference comes from interference effect. Given a quantum particle at initial position x, we want to know the probability that it travels to a position x' in a time t. It can travel from x to x' by many different paths (with different reflections). Anderson showed that there is constructive interference between different paths when x' is close to x, and destructive interference when x' is far from x. Hence, the quantum particle gets trapped (localized) near its initial position, x. A notable exception to this general picture is provided by so-called chiral one-dimensional particles, which are allowed to move only in one direction by some kinematic constraint, so any reflection is forbidden.

Experiments last year have revealed a strange one-dimensional system [2] in which there are ***two chiral channels for electrons moving in one direction and only one chiral channel propagating in the other direction.*** As an analogy, imagine a road with two lanes going in one direction but only one lane going the other way. This is very different from the cases studied earlier, with the same number of one-dimensional channels in both directions (like a normal road with the same number of lanes going in both directions).

The goal of our project is to study the effect of scattering between the channels by disorder, and to check if Anderson localization is still possible in this system**.** For this we will teach you the transfer matrix method of analyzing Anderson localization [3], and work together to apply it to this new situation.

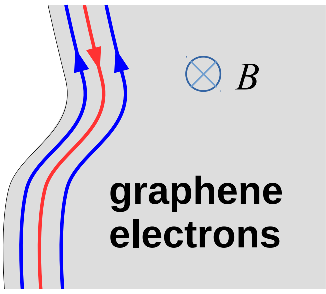
(a) Traditional situation, with one way to go to the right, and one way to go to the left.



This gives Anderson localization

(b) New situation, with two ways to go to the right, and one way to go to the left.

Does this gives Anderson localization or not?



[1] P. W. Anderson, "*Absence of Diffusion in Certain Random Lattices*", Phys. Rev. **109** 1492 (1958).

[2] A. Marguerite et al, "*Imaging work and dissipation in the quantum Hall state in graphene*", arXiv:1907.08973 (2019). In brief, the system is made by applying a very strong magnetic field B to graphene, so that it enters the quantum Hall regime. Then the electron motion in the bulk is blocked, while at the sample edge several one-dimensional propagating channels are allowed. The experiments indicate that the edge has the strange property mentioned above, where there are more channels propagating in one direction that the other.

[3] P. W. Anderson, D. J. Thouless, E. Abrahams, and D. S. Fisher, "New method for a scaling theory of localization", Phys. Rev. B **22**, 3519 (1980).