Qubit implementation in nanowire networks

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Let's discuss some real-life implementations of these topological quantum bits. The most pursued platform consists of semiconductor nanowires attached to superconducting leads where Majorana bound states emerge, and have the braiding statistics of the Ising anyons.

Immediately when we envision a pair of these states in a one-dimensional nanowire, we encounter a problem. We cannot exchange these two particles without colliding them. This would lead to fusing them, which then measures the quantum state, and hence loses quantum coherence.

The way to perform braiding is a clever workaround: if we attach an extra segment to the nanowire, we can move this topological object around, just like you do a Y-turn with your car. This allows for braiding of the two particles, orange and blue, as shown in the animation.

Since the presence of this additional arm is crucial for this research direction, there is actually a lot of development effort going into creating these structures. A few of these, published in scientific literature, are shown here.

Let's go on to the quantum state measurement in this scheme. Remember that a pair of Majorana states encode either zero electron or one electron charge, and these states are degenerate, that is they are the same in energy level. If we want to distinguish between them, we have to break this degeneracy.

If we close off the rest of the nanowire, the two states split off because of the charging energy of the system, just like for quantum dots built for spin quantum bits. Similarly, the two charge states can then be measured by charge detectors that are put close to the nanowire. This readout scheme, relying on the interaction between electrons in the nanowire, is called interaction-based operation.

What we need for this operation, is a set of valves, which we can open and close at will.

In real devices, these valves are electrostatic gates, which can locally control the flow of electrons inside the nanowire. When we apply a negative voltage, we remove the electrons and hence close the valve. On the other hand, when we apply a positive voltage on one of these gates, we open the valve, and let the electrons flow.

We can also use this concept to perform braiding, so that we need not to physically move the Majorana states, as we did before. We start from a T-device with a pair of Majorana's in each segment. With three valves, we can control the coupling between each pair of topological segments, enabling interaction-based braiding.

The animation shows how to exchange, or braid states 2 and 3. Importantly, each Majorana state is always located at the end of each segment. When opening a valve, we create a longer topological segment, which shuttles the quantum state of the Majorana to the very end of this longer segment. With this device, we can perform braiding operations, and we can also perform state measurement. Therefore we have just sketched a prototype topological qubit.

As an outlook, let's see a few proposed geometries of topological qubits, similar to the one we have just discussed. As you can see, there are many different schemes, showing that this is a very active research topic. It remains to be seen which geometry will lead to the very first experimental demonstration of a topological qubit, and, eventually, a scalable system of these intriguing qubits.