Transcript Quantum Computation on Anyons

Now let's do quantum computation with anyons. If we want to develop a scalable quantum computer, we have to consider the DiVincenzo criteria:

We need a scalable system of quantum objects on which we operate. These will be our qubits. We first have to initialize our qubits. Then, we have to able to do several gate operations before this system loses coherence. We need a universal set of quantum gates and, finally, we have to measure the quantum state of each qubit at the end of the quantum algorithm.

So let's see how these criteria are fulfilled for a set of anyons.

As Michael has shown in his lecture, we create the anyons from actual electrons. Specifically, the Ising anyons we will discuss in detail later on, are created pairwise. Scalability is then provided by the ensemble of anyons we can create in our physical device.

The quantum gates, the unitary operations are linked to the exchange of these anyons. As we discussed in the previous video, we need the non-Abelian property of the anyons to perform quantum gates.

Let's see how the exchange of two anyons happens as a function of time. If we follow the path of the particles, it now looks like a pair of braided looms. This is why the quantum operations on topological qubits are called braiding.

Exchanging another pair of anyons leads to a different quantum operation.

Let's see a few examples, specifically for the Majorana bound states, which form Ising anyons:

We can create a Z gate by exchanging a pair of anyons twice.

On the same system, the exchange of another pair corresponds to an X gate.

Or the Hadamard gate can be performed by sequential braiding operations on these anyons.

It is important that these braiding operations are always discrete; they either happen or don't happen. As a result, the quantum gates that we create here are always perfect; their fidelity is 100%.

There is however a catch: with discrete braiding operations we cannot reach the entire Bloch sphere of a qubit so some quantum gates required for universal quantum computation will be missing from the set that we can do with braiding. These additional gates can be supplemented by topologically not protected operations on the qubit, but with a less-than-100% gate fidelity.

And finally after all the quantum operations we have to measure the state of the qubit. This operation is called fusion, which happens when we merge, or fuse these particles. This behavior of the anyons is described by their so-called fusion rules.

In our case, that is the Ising anyons, this can result in a single electron (that is one elementary charge) or no electron (zero charge). We can then distinguish between these two states with charge sensors, as it is done for instance for spin qubits.

In the next video, we will see this happening in a physical system.