Transcript What are anyons? - Attila Geresdi

To understand the importance of anyons in quantum computation, let's take two identical elementary particles.

Quantum mechanics dictates that their state is described by their joint wavefunction.

If we now exchange these two particles, then this wavefunction picks up a phase, denoted by α.

If we now exchange them again, then we pick up the same phase, α, once again.

In our three dimensional world, we are now back to our original wavefunction.

It then follows that we only have two types of elementary particles: α is either zero and after two exchanges we also have zero rotation, the wavefunction that we started with.

This α defines bosons, such as photons.

Alternatively, α equals to π, and after two exchanges, we rotated the wavefunction with 2π, which is a full circle.

In this case, we have fermions, such as electrons, protons, neutrinos.

In two dimensions, this picture changes dramatically, because the particles can keep track of how many times they were exchanged around each other.

Therefore we lose the previous restriction of α, which only allowed for two types of elementary particles.

In two dimensions, the α phase can be anything, and we have a different set of particles for every α.

These particles are called anyons.

More generally, the exchange operation may be a non-trivial unitary operation, which brings the system to a new quantum mechanical state after each exchange.

As these operations generally don't commute, we call the associated anyons non-Abelian.

As a side-note, I mention that this expression comes from group theory in mathematics.

Now we have a connection to quantum computation: every quantum gate is a unitary operation, so we will somehow have to harness this non-trivial exchange operation to execute quantum algorithms with these particles.

We will discuss this in the next video.

Now let’s take a set of these non-Abelian anyons.

A key property of this system is that it has multiple quantum mechanical states with same, lowest energy.

In other words, it has a degenerate ground state.

The ground state is separated from the higher, incoherent energy levels by an energy gap.

To perform coherent operations, we want to stay in the ground state of the system.

Our exchange operation then moves the system from one ground state to another.

This means, that these states define a quantum bit, which is free from relaxation: since it is in its ground state, it cannot lose energy to its environment.

It also cannot gain energy from its environment, because of the energy gap above the ground state.

We created a qubit which is protected from noise or thermal fluctuations from its environment as long as those are smaller than the energy gap.

The size of the gap depends on the physical implementation of the qubit, and it is one of the most important parameters to optimize.

Furthermore, small changes in the exchange path don’t matter; if we exchange the same set of particles, we always do the same quantum operation.

And as a result, we can now understand why operating on these quantum particles can lead to perfect quantum gates: if we slightly change the exchange path because of external noise, or control infidelity, our quantum operation remains the same.

This property is usually referred to as the topological equivalence of the exchange paths.

In the next video, we will see how the non-Abelian anyons fulfill the requirements of building a quantum computer.