Slide 1

Hello everyone! Thank you for watching this video.

In this video we will look at some of the strange but interesting aspects of quantum mechanics, namely superposition and entanglement. We will do this by using IBM's real quantum computer, yes, a quantum computer is already in existence.

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If you have watched my previous video called transom introduction, the link is down below in the description, I hope you might have learnt a little bit about the basic building blocks of quantum computer, called transmon. I think I focused a lot on the physics of transmon, and in the end I didn't even have time to talk about the quantum computer itself. So in this video I hope to remedy that.

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Like I said, a real quantum computer is already in existence. It is built by IBM, and we can all register for an account here for free (jump to slide 4) and start playing with it.

Slide 4
As you can see here I have built myself some quantum circuit that I hope it can do addition for me. By the look of it, it doesn't look quite right (chuckle…). It's a mess. So let's start with something simpler.

Share Screen starts.
Let me share my screen. As you can see I'm on the IBM quantum computer page. And it's a clean slate. We see on the right hand side, lines called q0, q1 and q2 etc. These are our qubits, they can be either 0 or 1, or a superposition of 0 and 1. Currently, the qubits are in well defined sate, for instance, all the qubits here start in state 0. Let's put this meter looking unit down here, and it measures the state the quit is in. And as you can see the quit is 100% 0. There is no other possible value. So this is a well defined state,

Now let's delete the measurement, and put down this Hadamard gate beside our qubit, what this gate does, is it scrambles our qubit, now it is neither 0 or 1, it is a superposition of both! Let's measure it now. We put down the measurement unit, this completes our quantum circuit yay! And let's send it to the real quantum computer. I'm doing this at night now, so hopefully there won't be any queue. Well the queue is not very long. This is usually what happens, you have to wait a little bit for your job to be processed.

Luckily, I have done it already. So here is the result, let's go back to the slides.

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What the result tells us is that there is a roughly 50% chance of finding the qubit in 0 or 1. That's what the Hadamard Gate does for us. But it's not perfectly 50% as you can see. Why? Because the quantum system is random, you can't expect it to give you 1 0 1 0 alternatingly, amounting to a perfect 50% probability for both outcomes. Most likely, it will be a totally random series of outcomes, 1 1 0 0 1 0 1 etc. And that you might think is bad. But it can have a surprising usage in cryptology, that is the art of sending secret messages. In cryptology one needs a random number generator to generate a random key, to lock and unlock a secret message. The problem is, random number generators are in fact based on mathematical algorithms, they're not truly random. There are patterns, and hackers can find out the pattern with their computers and thus unlock the messages not meant for them. Now with this quantum computer we can repeatedly measure the out come of this simple circuit and get a

set of truly random numbers. That is why you hear a lot about using quantum computer in cryptology. Its randomness is its advantage.

Screen share starts again.
Ok, now let's go back to our IBM quantum composer. We have seen what a single qubit can do, But obviously the quantum computer has many qubits in it. Not just one. So can we somehow make them interact with each other. Yes we can, we can use these quantum logic gates, I don't know many of them, but this one I know, it's called a CNOT gate, let's put it down like so. We keep the Hadamard gate on q0, this puts q0 in a superposition state of 0 and 1. And we put down our CNOT gate here connecting q0 and q1. q1 is in a well defined state 0. The CNOT gate works as such, if q0 is in 0 state, it does affect q1, but if q0 is in state 1, then, whatever the state q1 is in, it will be flipped! So for instance, if q0 is in state 1, and q1 is in state 0, as we know, after passing through the CNOT gate, q1 will end up in state 1. So if we measure both qubits, the only two possible outcomes are q0 and q1 both in state 0, and q0 and q1 both in state 1. There is no other such as q0 in state 1 and q1 in state 0 etc. We see this in the graph down here. This is not the measurement result, this is a simulation of our measurement result in an ideal case. So state 11 and state 00 are the only two possible outcomes and they're equally likely.

We can of course do a measurement on them on the real quantum computer and see what we get. Again I have done this measurement, so we don't have to wait. Just a few months ago when I started using this IBM quantum computer I don't think there are these many people. It's a good thing, many people want to try something new.

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We see that indeed 11 and 00 are the two most likely states, they are not perfectly 50% because of quantum randomness as we discussed. But slightly troubling is that we also see there are probabilities for other states to exist. These are due to environmental noise, the two qubits are also interacting with the environment which can also alter their states. The probability is small in this case. The IBM quantum computer is well built.

We call these two qubits entangled. Because their states are not independent of each other, in this case, the two qubits are always in the same state, If one of them is in state 1 then the other must be too, and vice versa.

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Now consider this thought experiment, let's say, instead of having two qubits entangled, let's have two particles entangled, and after that, they go their separate ways, but still they're entangle, so if we measure one of them to be in a certain state, the other particle must be in that same state too when we measure it as well. It 's hard to imagine qubits moving apart, since they're parts of the same quantum computer. Anyway in this thought experiment, suppose they move really far apart. And we measure them at the same time, maybe one of the particle is still on earth, we can measure it. and an alien collaborator is measuring it on a far far away planet. If we measure the particle to be 0 state, then the alien scientist will simultaneously also measure 0 state,

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and if we measure the particle to be in 1 state, the alien scientist will also simultaneously measure it to be in 1 state. There is no other way, the two particles must be in the same state, so even if they are far apart, if one of them is found to be in one state, then the other immediately switches to that state as well! How do they know what is happening to the other particle? And how could they know instantaneously?

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This is called EPR paradox. And surprising, people can prove experimentally, this is indeed the case, the influence of quantum mechanics can travel instantaneously across the universe.

Does this mean we can transfer information at a speed faster than the speed of light with our quantum computer, yes coming back to our quantum computers. Unfortunately no, but this strange behavior definitely had people thinking, and there are attempts to make use of this behavior in information transfer, such as superdense coding where one qubit can transfer the information of two binary bits. But that is another rabbit hole and we are way over time.

In summary, quantum mechanics and quantum computer offers a whole new world for us to explore, let's not be afraid. And here I might add personally, I do hope this faster than the speed of light action can lead to faster than the speed of light travel, that is my wild dream. Thank you!!