[SQUEAKING] [RUSTLING] [CLICKING]

PROFESSOR: Welcome back to 8701. In the second chapter, we will discuss symmetries and the importance of symmetries in physics in general, but also especially in particle physics and nuclear physics. So we start with a short introductory video, and then we'll move on to more details as we go along.

The importance of symmetries cannot be understated in physics. And there's two aspects which are important. The first one is that symmetries and conservation laws go hand in hand, as discussed by Noether's theorem. To express the theorem in an informal way, you can say that if a system has a continuous symmetry property, then there are corresponding properties whose values do not change with time, meaning that they're conserved.

You can express this more sophisticated, and say to every differentiable symmetry generated by local action, there's correspondence. There's a correspondent conserved current. And we're going to look at those actions and currents as we go along.

The second aspect, beyond the fact that there's conservation laws, is that you can understand physics experiments and nature if you know that physics has an underlying symmetry, without fully understanding the physics or the mathematical backgrounds in order to do calculation in detail. So knowing that there is underlying symmetry can help in really expressing or understanding the physics behavior of experiments.

A few historic remarks on Emmy Noether-- Emmy Noether was born in Germany in the 1880s in Erlangen, where she grew up and also studied Mathematics at the University of Erlangen. After getting her degree, she worked for a full seven years at the university in the Math Department, and received zero dollars, and not just because it wasn't the currency being used there, but at that time, women didn't really have a prominent role in academia. And so there was no job for her to take.

But her talents and her qualification was seen in the mathematical world at the time, specifically in the center of the mathematical world, which was in Goettingen. So Hilbert basically discovered her, and asked her to come to Goettingen. In order to do habilitation, she did get an habilitation in Goettingen in 1919, and then stayed in Goettingen till the situation in Europe degraded in the 1930s.

She was born Jewish and couldn't stay in Goettingen beyond the year 1933, and then had to immigrate into the United States, where she worked at Bryn Mawr College, and also with Princeton. Her work-- you see here her habilitation, which is in German [SPEAKING GERMAN], "Invariant Variation of Problems," was highly regarded. And she had a lot of influence and impact on various strands of mathematics and physics.

Unfortunately, she passed away already when she was about 50 years old. She was diagnosed with some sort of cancer, and passed away really, really quickly after this, after some surgery. Her temperature rose and a few days later, she passed away.

To come back to symmetries and conservation laws, every symmetry of nature uses a conservation law. That is what Noether's theorem tells you. And you can reverse this to saying that every conservation law in physics reflects an underlying symmetry.

And examples for this are the fact that the properties, the laws of physics are invariant on the time translation, meaning that physics is the same yesterday, the same tomorrow, and it's going to be the same next week. And out of this, we can deduce energy conservation. Similarly, translation in space results in a momentum conservation, angular rotations or rotations without the angular momentum.

And then a little bit harder to grasp, but we will see this in more detail, internal symmetries can also lead to conservation laws. And gauge transformation leads to the conservation of charge. So there is internal symmetries as well.

Before we dive into more detail, a few things. First, in many cases, symmetry operations can be expressed via matrices or groups. And there's a few rules or operations which are rather important and define symmetry.

The first one is that any symmetry operation has to have identity, meaning there has to be an operation which doesn't do anything with an element of this group. There has to be closure, meaning that if you apply a first transformation and then a second, the resulting transformation is, again, part of the set of transformations. And there is an inverse, meaning that if you rotate in one direction, you can rotate back.

And there's associativity, meaning that if you have a rotation acting on two other rotations, you can regroup and follow what's shown in this equation here. It's not clear that you can reverse the order of certain elements of your group or your symmetry operation. You can classify them, however.

Those where you can commute, those are called abelian groups, and those that you cannot, those are non-abelian. All right, so with this, we have introduced, with the first video, symmetries. And now, we just dive into more detail in understanding continuous symmetries and also discrete symmetries, and what we can learn from them.