MARKUS KLUTE: Hello. So with this recording I'd like to introduce the topic of flavor symmetry, what we mean by that. So when the neutron was discovered, it was noted that the mass of the neutron is very close to the mass of the proton. And so it seems like those two particles are somehow related. Even so, the electric charge is different. The proton is charged, the neutron is neutral.

And you can see here that the masses are really very, very close, about 1 MeV or about 1% difference in mass. So Heisenberg proposed, and that was in the 1930s, to regard them as two states of the same particle. They were really so different that you could think that they are basically the same, just a rotation from one end to the other. And that's exactly what he did, considering them as one particle, a nucleon, where the proton is described as a doublet, with an up doublet, and the neutron as a down doublet, similar to an up quark and a down quark in electron and neutrino later on. Those particles were not known at the time.

So he introduces a new concept, so-called isospin or strong isospin, where he's doing exactly the this. He labels the proton up, and he labels the neutron down. So, so far, we haven't done anything, but introduce new labels for new particles or particles, new particles at the time.

But now if you assume that the strong force is invariant under rotations in this isospin space, meaning when you flip the neutron into a proton and vice versa, those rotations are invariant. The strong force is invariant under those rotations. That means or it follows directly that the isospin is conserved in all strong interactions. So that is what really the conclusion is of this introduction of those new labels is that isospin is conserved under strong interactions. So this was proposed in the 1930s.

Again, we noticed the symmetry in nature. And from that symmetry, a conservation follows. Even so, and we can conclude in physics cross-sections or ratios of cross-sections from it, without understanding in this case, QCDs a strong interaction. So this is very fascinating. And you can just apply this concept now to other particles, for example, the pion.

The pion has an isospin of 1. And there are three pions or three states-- the 0 state, the up state, and the down state, which is pi plus, the pi 0, and the pi minus. In general, you can conclude that the multiplicity of your particles, as you see the neutron and the proton, the pi plus, the pi 0, and the pi minus, the multiplicity is 2 times the isospin plus 1. Isospin equals 1 means that the three particles as part of the representation. So far so good.

So later, this concept was moved to other new particles. Many new particles were introduced and produced in the emerging accelerators and experiments on the market. And people tried to classify them by the isospin. Gell, Mann, and Nishijima empirically observed that there's a relation which holds, this equation here, which is that the charge, if you assigned the maximum value, I3, the third component of the isospin, to the member of the multiplet with the highest charge-- in the previous example it was the proton or the pi plus. Then the charge of this particle follows from the isospin, the baryon number, and the strangeness.

We looked at baryon number and strangeness before. As a reminder, strangeness is the number of strange quarks in the baryon or the meson, and the baryon number is simply the number of baryons. So if you just look at this, for example, for this pion case, we had the isospin equals 1, baryon number equals 0, strangeness equals 0, which follows that the maximum charge involved is 1, which is a charge of a positively charged proton.

So far so good. This was empirically observed. But once you then later discover and develop a quark model-- this is then in the 1970s-- you can deduce this equation directly from the assignment of isospin to quarks, which is rather fascinating. Again, we don't understand the physics fully. But just from the symmetry you can, and empirically you can deduce information about physical systems.

However, if you try to now extend this idea of isospin to the complete quark model, you find that the symmetry starts to be broken. It already starts to be broken slightly, when you include strangeness or strange quarks. But it's badly broken when you include charm, bottom, and top. And the reason can be seen here.

The up quark and the down quark, both of the particles making up ions and the neutron and the proton. And even if you include strangeness, the different in mass is not very large. So the symmetry, the particles really look like they're the same particle in a different state of the same particle. But when you introduce other quarks, heavier quarks, charm and bottom, you find that the mass difference is so large, that the symmetries are broken. So this concept starts failing because of the large mass differences, because the symmetry is broken.

All right, so from here, we now go to discrete symmetries. And again, from the observation of those symmetries, we can deduce physics without fully understanding the underlying physics.