**MARKUS KLUTE:** Welcome back to 8.20, special relativity. Let's start here with a short summary. We have seen through experimental measurements that there is no ether, that electromagnetic waves travels through vacuum. We have discussed the concept of the relativity of simultaneity, meaning that two events might occur simultaneous to one reference-- in one reference frame, to one observer, while they're not to another.

In the last two videos, we looked at clocks. And we've seen that moving clocks run slow. We've also seen that moving objects appear smaller. They're lengths contract.

We found that the time of a moving clock is related to the time in the clock at rest with a gamma factor because it's time dilation. And, for the length, we have seen that there is a 1 over gamma dependency, length contraction.

The entire discussion was based on Einstein's postulates. We simply used Einstein's postulates. And then we looked at experiments of clocks.

Now, you might argue that the setup of the clock is actually what's tricking us here, but I can tell you that is not the case. As you have seen for the muon, the muon doesn't know about optical clocks. It just decays based on its own properties. I think it's fair to say that Poincaré and Lorentz came to similar conclusions about the same time as Einstein did.

Delta t at rest and delta L at rest, the time and the length, are also sometimes called the proper time and length. In German-- and I actually prefer this a bit-- we use the word eigen, which means own. So it's basically the time, the own time of the object, the object being addressed.

So we can now ask, [INAUDIBLE] seen time is suspect. What is not suspect? What are the observables which are invariant? And, by this, I mean the observables, when we have two different reference frames and we have a conversation, we do actually agree in a conversation about an observation we have. We have seen we cannot agree on time, and we cannot agree on the length in the direction in which we are moving.

So can I ask, for example, what happens to the width or the height? If I put a train on a train track and it's fast moving, is that contracted or even expanded or changing at all? The answer is no.

Similarly, if I put a train track on a track and I go very fast into a tunnel, does the height of the tunnel change? Also here the answer is no. And we can verify this later quantitatively.

In summary, transverse dimensions are not affected. They are not suspect. We can agree in a conversation of two people in different reference frames about the height and the width of a train. That's good.

But what else is invariant? So here I want you to consider the time and distance between two events or maybe even three events observed from different reference frames. And we introduce or reintroduce our characters Alice and Bob and add Carol to this. So we're going to have three reference frames of three observers in this discussion.

So I want you to look at this one here. So assume that Bob has a clock, and it's moving with a velocity v. And Alice is observing Bob's clock. We have done this before. Now, we want to also add Carol to this. And Carol is moving with three times the velocity and is also observing Bob's clock.

What I want you to do is look at this property here. So we have seen that the height is invariant. So let's look at what happens if I calculate 2 times the height squared, and I use x and t, time and space, in order to express the height, all right? Again, this is an opportunity to stop the clock, stop the video, and work this out on a piece of paper.

So it turns out it's not that hard. We basically find that 4 times the height squared is equal to-- maybe it is hard-- c squared times t squared minus x squared. And, since the height is an invariant, this property, c squared, the speed of light squared, times the time squared minus x squared, is invariant.

So we can think about them as delta t and delta x. When we look at the difference in time and the difference in space between two events-- Professor Klute entered the class. And, at the other end of the class, Professor Klute exploded. If I do the delta t and the delta x between the two-- we square them and subtract them-- that is an observation we can all agree on.

Whether or not you're stationary in the classroom or you're passing by really quickly with your spacecraft, that observation is something we can agree on. And it's invariant. This property is called the invariant interval.