MARKUS KLUTE: Welcome back to 8.20 Special Relativity. In this section, we'll talk about waves. You have all seen waves. You know what a wave is in principle. You might have had an opportunity to surf on a wave just like the one behind me. What we want to do here is be more quantitative and more precise in the definitions, and also look at different sorts of waves.

I find this Wikipedia article here quite interesting. It starts with saying that, in physics, a wave is an oscillation accompanied by the transfer of energy that travels through space or mass. It continues then talking about the various types of waves, and it makes a distinction between mechanical waves, which travels through a medium or substance, and the deformation of the substance is reversed by restoring force.

In contrast, there's electromagnetic waves, which we have just seen in the previous section. They do not require a medium, and that is topic of the next section as we continue the discussion of special relativity. Here, the electromagnetic waves consist of an oscillation of electrical and magnetic fields, which are generated through charged particles.

Things that don't require a medium, they can travel through a vacuum, but an electromagnetic wave can also travel through a medium like water or anything else you come up with. It doesn't stop there really, because the concept of waves are really everywhere in physics. Specifically, when you start studying quantum mechanics and the behavior of particles, those are described by waves.

Really exciting recent results are those of the discovery of gravitational waves, which are vibrations or movement of a gravitational field. Also those don't require a medium. They travel through vacuum. When we look at waves, we can start characterizing them, and one primary sort of characterization is the polarization of a wave, meaning whether or not the oscillation itself happens in a transverse way with respect to the direction of movement, or longitudinal to the direction of movement.

Mechanical waves can be transverse and longitudinal, polarized, or have transverse and longitudinal components. Electromagnetic waves in free space are transverse only. So here's a picture of a wave, sine or cosine, and we can start with the characterization. One aspect is the amplitude.

How big is, for example, the water wave? How big is the maximum strength of the electric or magnetic field? That's the amplitude. Waves propagate and they have a velocity. That is a characterization. The length of the wave, the wavelength, is another way to characterize them. In physics, it's always important to understand the units of the object we discuss.

Here, just as a reminder, the velocity given in meter per second. The frequency of your waves. So how often do we find a trough, for a wave for example, per second. The frequency 1 over second. The wavelength is in meters. We can continue with the characterization and be a little bit more complete. We can start from the medium, the period, the polarization, transverse and longitudinal, the wavelength, frequency, velocity, or even how much energy is being carried by the wave.

When we compare waves and look at their properties, we have to consider the phase of the waves. So where do, for example, two waves line up, the difference in phase between two waves, and some waves can interfere. So if you have two waves which interfere and they are out of phase, like the one drawn in this picture, the resulting wave has amplitude 0. This is called destructive interference.

You can have constructive interference. For example, when those two waves are aligned, there's no phase difference, and then the amplitudes you simply add. The situation can be more complicated. When we study the speed of a wave, there are a number of considerations.

The first one is that the speed of a wave depends on the medium in which it travels. And the study of the speed or the velocity dependent on the medium is part of what we will discuss in the discussion of whether or not there is a medium responsible for carrying electromagnetic waves.

The source. So for electromagnetic waves, you have a charged particle. Does the speed of the source change the speed of the wave? The answer is no. It changes the wavelength or the frequency, but the velocity is not changed, and you find this, for example, in sound waves in the Doppler effect.

When you listen to a police car, you hear that the frequency changes depending on whether or not the police car is coming towards you or driving away from you. That is called the Doppler effect. That does not change the velocity of sounds in air. That's independent. When your medium is moving, that changes the velocity, and so here you have to add the velocities of the medium.

So for light, as a summary, light is an electromagnetic wave which is moving in vacuum with speed C, and that is independent of the source. But you can ask, in which frame. In which frame is that the velocity of light, and what is the medium, and that is really the discussion we want to carry on from here.

At the time, when Einstein developed special relativity, there was still a discussion going on whether or not electromagnetic waves are of the nature of a particle or of the nature of a wave and whether or not that wave moves in a medium, which was called ether. So we can then experimentally determine this.

We can look at various properties of our waves and ask whether or not this is consistent with the hypothesis that this is a particle, this is a wave in ether, maybe both, maybe neither. And we can then fill a table like this one here and answer the question. So this is, again, an opportunity for you to stop the video and think through this and try to answer the individual questions.

I do this here for you. One characteristic of light, at least when there is no heavy masses involved, is that it travels in a straight line. That is certainly consistent with light being a particle, but it's also consistent with it being a wave. So the answer is both are correct. Interference and diffraction pattern. That's rather difficult to describe for a particle model, but waves, as we just saw, can interfere, and there can be diffraction.

Polarization. What does it mean for a particle to be polarized, but waves can be polarized. We have just seen transverse and longitudinal polarization. Light velocity depend on the velocity of the source velocity. For particles, it doesn't seem to hold. For waves, this does. And then, the last, is the speed of light greater in air than in water.

That's true for a wave. For particles, you might argue this one, but I put a no in this table here, which means that in our discussion up to this point, clearly the hypothesis of a wave for light and ether holds. You'll see in the next sections that there is aspects of light where the discussion will not hold like this, especially for the ether hypothesis.