SHAOUL EZEKIEL: The light beam from a laser is as close to an ideal beam as one can get. What I mean by that is that the properties of this beam, the propagation properties, are limited by fundamental laws of physics-- for example, loss of diffraction-- and not by the properties of the light source.

For example, a laser beam from a well-behaved laser can be collimated to a very small angle. This angle is determined by, as I said, the laws of diffraction, which is the wavelength of the light divided by the diameter of the beam. And it doesn't say anything about the size of the source or the properties of the source, and that is the ideal collimation limit on a beam.

At the same time, a laser beam can be focused to a very small spot. The size of that spot is, again, determined by laws of diffraction, which is the wavelength of the light divided by the diameter of the beam, multiplied by the focal length of the lens. And if we choose the diameter of the beam and the focal length of the lens about equal, then the spot size would be of the order of the wavelength of light. And again, it doesn't say anything about the physical size of the light source or what have you, as we would have in a case of an arc lamp or any other kind of light source.

Now, in these demonstrations that follow, we're going to illustrate some of these basic properties of laser beams. What we're going to start with is this laser here, which is a helium-neon laser, and here is the beam from the laser. We're going to reflect it by this mirror here and then reflect it again by this mirror here and let the beam fall on the screen.

Now, you might be able to get a better feeling for the beam if I use the black card. Maybe the colors will come out better. So here is essentially the beam coming out directly from this laser. And it's very difficult, very difficult to tell what's going on. It looks pretty collimated.

Now, what the first thing I'm going to do is expand the beam and see what it looks like. So I'm going to take a short focal-length lens and I'm going to place it in the way of the beam, and here on the screen now, we see the expanded beam. Now, if we go take a close-up, we can see that it's got rings and what have you. Now, these rings that you see or these fringes are due to the fact that the laser beam has to go through optical components, like the output mirror of the laser, it has to be reflected by these mirrors and then has to pass through this lens over here, and they all corrupt the laser beam.

But we can easily get rid of these effects by placing a pinhole. Here is the-- here's the pinhole. And what I can do, I can just place the pinhole in front of this lens, where the focus of this lens here, and if I have my adjustment right, I have then so-called the spatially filtered laser beam. As you can see on the screen now, we got rid of the-- all these rings, and this is as close to an ideal laser beam as one can get.

Now, what we see here is the speckle. So if I move the screen a little bit, you can see I can wash out the speckle. So when it's still, you can see the speckled pattern because the surface is not smooth. But otherwise, you don't see any fringes on the beam.

And also there's an intensely distribution, which is essentially Gaussian squared. The field is Gaussian, but the intensity distribution is Gaussian squared, so that essentially drops off to zero in the wings. All right, so this is a so-called spatially filtered laser beam, and for some experiments, it's very important to spatially filter the beam, especially in interferometry and what have you.

Now I'm going to-- well, no. Before I do anything else, I'm going to show you that the placing of the pinhole is very critical. If we can now take a close-up of the spot-- now if I move the pinhole slightly, you can see that first of all, the beam disappears because this pinhole is only of the order of about 12 microns or so.

And another point that one has to watch out for when using such a pinhole as a spatial filter is that if the pinhole interrupts any part of the laser beam, the-- now, let's look at the insert again-- that this Gaussian distribution in the beam gets affected, and you will start to see all kinds of diffraction rings. So again, for the special filter to work, the pinhole must not cut any of the essential part of the laser beam.

Now, what I'm going to do is collimate this beam of light. And here what I will use is a simple two-lens collimator, and I'll place it over here. And here it is. Here's the output from the collimator on the black card and see that-- obviously, you can't check on the exact collimation, but you can see that the beam can be simply collimated. All right.

Now, the next thing that one sometime wants to do is to focus the laser beam. Again, if I take a simple lens and again place it in the beam, now I can focus. Let's look at the beam again. I can focus to a tiny spot and back out again.

Here we are. Focus to a small spot. Now, it's very difficult to see the size of the spot or even the shape of this focused Gaussian beam. Remember, I said before that it can be focused to the spot size of the order of the wavelengths of light, and it's not so easy to see it on this card.

So what we're going to do when we come back, we're going to get a water tank and pass the light beam, the focus light beam-- laser beam into the water tank, and we'll add some scatterers to enhance the scattering from the laser beam by the water, and then you'll see you get a better picture for the focusing of this Gaussian laser beam. So when we come back, we'll have that all ready for you.

We have now placed the water tank in place so that we can pass the laser beam through it and visualize the laser beam as it passes through the water. We've also-- here is the tank, by the way-- and we've also added a few drops of milk to enhance the scattering, and that's why the water looks murky. In addition, we've tilted the tank a little bit so that we can get a better angle for the camera.

Now, the setup is just like we had it before, but let me remind you of it. Here's the laser, here's the beam from the laser reflected by this mirror here. Then we pass it through a polarization rotator here, so that we can adjust the polarization for maximum scattered light for the camera. And then the output after the polarization rotates gets reflected by this mirror here into this short focal-length lens, the spatial filter we had before and then the collimator. The output of the collimator is here before it goes into the tank and then out here after it leaves the tank

Now, in order to visualize the beam as it propagates in the water, we'll have to turn the room lights down, but let me tell you what I'm going to do when the room lights are down. I'm going to first look at the collimated beam in the water. And then I'm going to take this lens and another lens like this, and I'm going to place it over here, so that we can focus the light into the tank. All right, and then we can explore the region around the focus. So now we're ready to turn the room lights down and look at the region around the focus by simply observing the scattered light in the water.

Now that the room lights are dim and the camera focused into the tank, the first thing we see is the collimated beam or the scattered light associated with the collimated beam. There's not much I can really say about that. More interesting is when I put a lens before the tank and look at the focal region.

Here we are. I'm going to adjust the position of the lens, so that the waist or the focused region, the focal region, is in the center of your screen. Now, the thing that you can observe is that laser beam coming in from the left then is then focused to a region where the spot is small, spot size is small, and then expands again on the other side.

Now, because of the limitation of television recording, especially recording of color and especially red, you do better. If you want to see how narrow that focal region is, you do better if you turn down the color, turn off the color, and look at it in black and white. If you do that, you'll see that the focal region is now narrower than it is when it's red. But in fact, the truth is that you cannot really observe this way the true size of the focused spot because that's only a few microns, and it's going to be limited by television resolution in any case. But at least you get a feel for the fact that the beam is pretty narrow at the focus.

Another thing you want to observe is that the region around the focus is reasonably constant in diameter, and that's called the Rayleigh region, where the expansion of the beam is not so big. But after that, then the beam expands one side and then symmetrically the other side of the beam. The intensity distribution, if you take a slice anywhere along the beam, intensity distribution is still Gaussian or Gaussian squared. The field distribution is Gaussian and intensity is Gaussian squared.

The other thing to observe is that the curvature. Now, at the focal at the focus or at the middle of that Rayleigh range, what we call the focus or the waist of the beam, the curvature is-- the radius of curvature is infinite, which means that we have a plane wave. Now, it stays plane within the Rayleigh region or close to plane, and then we develop the coverage, so we have an expanding beam on one side and expanding beam on the other side. In fact, if we go far away, the curvature, the radius of curvature, is the same as if we had a spherical wave starting at the waist. All, right that's with this lens.

Now I'm going to take this lens off and place another lens that is a little shorter in focal length. And here we are. Let me turn it around and then let me again center it, so that the waist is the middle of your screen, and see now the divergence is different, showing that it's a shorter focal length net and I find. Over to one side, you can see that the beam gets quite big very quickly and also the same to the other side.

And then the other thing you notice is that the Rayleigh range or the region around focus now is smaller, so it's a tighter focus than in the previous case. And as the focal length of the lens gets bigger and bigger, then the Rayleigh region gets bigger and bigger also. So here we are with a shorter focal length. And again, if you want to see a nice, small focal region, then you want to turn down your color and look at it in black and white.

So in summary, we've illustrated some of the basic properties associated with the optics of laser beams, such as collimation, focusing, and what have you. Also we've shown that the use of a spatial filter can help clean up the laser beam, and it looks very beautiful after that. But in order to really measure the properties of the laser beams and measure the exact size of the focus and the exact collimation, degree of collimation, one really needs to use more precise methods, such as taking a tiny pinhole of the order of 1 or 2 microns in diameter and then scanning it across the beam at various locations. Otherwise, it's only approximate. But I think you'll get a feel for these properties in these-- of the laser beam in these demonstrations.