SHAOUL EZEKIEL: Now we are all set to look at the spectrum of laser light. For example, is the spectrum-- is it a single frequency? Or is it multiple frequency? Or what have you? In fact, we're going to look at the spectrum of light from two lasers, two helium neon lasers.

We have this laser here with external mirrors and the one over here with internal mirrors. And the way we're going to look at the spectrum is by using the optical spectrum analyzer here.

So now let me turn on this laser with external mirrors. And the light from the laser, then, is reflected by this mirror and this mirror. And here it is going right into this optical spectrum analyzer, which is a scanning Fabry-Perot cavity. The output of this spectrum analyzer then goes to an oscilloscope over here.

As we can see on the oscilloscope, we have more than one frequency. In fact, we have several frequencies, sometimes three, and sometimes even four. The spacing of the modes here is about 270 megahertz, which is consistent with the length of the laser cavity of 56 centimeters.

Now, the first thing I'm going to do is see whether the polarization of all these laser frequencies is the same or not. So what I'm going to do is insert the polarizer in the beam and then rotate the polarizer. In fact, let me up the gain a little bit here. And let me rotate the polarizer or the transmission axis of the polarizer to see whether the polarization is the same for all of them. And, as you can see, I can extinguish all of them when the polarization is horizontal and bring them all up when the polarization is vertical.

And remember, this is the light that was plane polarized. So now we've shown that, indeed, all the frequencies that come out from this laser, all of them have the same polarization, the polarization in the vertical plane. So let me take the polarizer out and readjust the gain on the scope.

So back now to the three frequencies-- you can see that they move around. Because the cavity is drifting in length due to the air currents, or temperature effects, or what have you. And even, in fact, as I speak, or as I tap on the cavity, you can see that I can create a mess of the spectrum just by simply tapping. Or if I lean on the table, you can see, again, that I can make the frequencies wander around.

Now, the fact that I have more than one frequency means there is enough gain for several frequencies to oscillate due to the fact that the gain medium has some bandwidth-- not very huge, but some bandwidth. Now, I can make the laser go at one frequency by introducing loss, by simply misaligning the cavity to introduce loss. So you can see here I've got only two frequencies. And, in fact, I'm going to up the sensitivity of the scope. Because the power goes down when I misalign.

You can see here, I have, essentially, two frequency. And if I add more loss, I can have only one frequency. So in a way, I can run this laser at one frequency. But it's difficult to keep the other one out. And then you can see that as I lean on the cavity, I can make this frequency move around.

Now, generally, that's not a good way of getting single frequency. And we have other techniques for getting single frequency, which we'll discuss later. For this laser, it's best to align it for the highest power out. And this way we'll automatically get more than one frequency. And for a lot of applications, this is fine.

All right, so to summarize, then, this laser that is 56 centimeters long, or the cavity is 56 centimeters long, then gives us about three modes. And the spacing between each mode is about 270 megahertz. And all the modes have the same polarization.

Now we're ready to look at the other laser, the laser that has internal mirrors and also shorter in length. So when we come back, then we look at that laser.

Now we're ready to look at the spectrum of this laser here with internal mirrors. The set up for looking at the spectrum is the same as before. But let me just remind you of it.

Here's the output of the laser reflected by this mirror, this mirror, into the scanning Fabry-Perot cavity. The output of the cavity then goes onto the oscilloscope over there. Now, as you can see on the scope, and let me adjust the-- center the scan.

As you can see, we have two big modes. And these are spaced by 680 megahertz, which is consistent with the length of the laser cavity of 22 centimeters given by the-- 680 megahertz is given by c over 2L, the spacing between longitudinal modes. So these are two longitudinal modes of the laser. This little fellow here is a third mode that's coming in at an odd position because the free spectral range of the scanning Fabry-Perot cavity is not quite large enough. So we're getting a wrap around from another order. So let's not worry about this one too much. So let's look at, essentially, the two main longitudinal modes of this laser.

Now, let's look at now the polarization of these modes. So now what I'm going to do is take a polarizer and, as we did with the other laser, let's take the polarizer and look at the spectrum. Now, if we look at the scope after I make a slight adjustment of the gain because of the loss in the polarizer, now what I'm going to do is look at the spectrum of the laser light on the scope as a function of polarization.

So first, you can see with the polarization set at this angle, you see essentially we have predominantly one mode. And then if I rotate the transmission axis of the polarizer, I can extinguish this mode and bring up the other one. Now, let me just center the mode on the scope so I can bring up the other one.

Now you can see, indeed, I have single frequency operation on just one mode. So I either have this mode here or, if I rotate the polarizer, I can bring up the other one. So again, let me go back to the first one and then to the one over here. Now, this is different from what we had with the laser with external mirrors and the Brewster windows where we found that all the modes were of the same polarization. Now here we find that one mode is one polarization. And the other one is polarized orthogonal to the first one. And, in fact, this explains why the output of the laser wasn't plane polarized as in the external mirror cavity.

Now, this is very interesting that because we have internal mirrors the modes have orthogonal polarization, at least adjacent modes have orthogonal polarization. And, in fact, this is a very easy way of selecting single frequency operation by simply placing a polarizer in the beam and then selecting one frequency. Now, let's look at this single frequency behavior.

If I want to tune the laser frequency, I simply blow some air onto the laser to-- I blew too much. Let me do it again. So you can see that I can scan the laser frequency by simply changing the length of the cavity. In this case, I'm cooling off the cavity.

Now, let me also point out that the line width that you see, the line width that you see here is not the laser line width at all. The line width that you see here is determined by the scanning Fabry-Perot cavity. The line width, the true line width of the laser is very narrow. In fact, in principle it's a fraction of a millihertz. But because the laser jitters and what have you, you'll get a little broadening, but certainly nowhere near as wide as what you see over here.

And again, let me bring up the other mode or the other polarization. And again, this one will also tune across the gain curve of the cavity. I mean a gain curve of the medium of the laser.

So in summary, then, we've seen that for this laser here that's about 22 centimeters apart, that we get longitudinal modes of 680 megahertz apart. And the polarization of each mode is different. In fact they have-- adjacent modes have orthogonal polarization. While with this longer laser of length 56 centimeters, we found that the mode spacing was 270 megahertz. Again, it's consistent with the length of the laser-- and that the polarization of all the modes was identical.

Now, I want to leave you with this puzzle. Why, in this case here, for the laser with internal mirrors, the polarizations of the modes were different while the one here the polarization was the same? Well, this is-- to answer this one here is easy because of the Brewster windows. And the only polarization that can laze is the polarization set by the angle of the Brewster windows.

But in this case here, we don't have any windows to set the polarization. We only have just two mirrors sealed onto the discharge tube. And we saw that adjacent modes have orthogonal polarizations. So here's a nice little puzzle for you to think about.

Now we're not done yet with laser properties. There are several other experiments that we have prepared for you. So when we come back, we'll show you other aspects of laser behavior.