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SHAOUL EZEKIEL: I'm sure you'll agree with me when I say that lasers are fantastic devices. In fact, every day we hear of more and more applications. I don't think there is a field that has not been touched by the laser.

Of course, most of us are familiar with supermarket checkout counters with the laser barcode readers, as well as laser disks and laser printers, and now, we're having laser fiber optic communication systems, but there are all sorts of other applications that some of us don't know too much about. For example, laser surgery is now becoming very important, as well as retinal welding, and so on, materials processing. When it comes to sensors or laser sensors, lasers can measure almost anything, and sometimes, they do it very well, for example, for navigation systems, laser gyroscopes that are used right now in launch some airplanes.

Also, we have things like 3D imaging using holography, which we've never had before. Even optical computers are now being taken a little bit more seriously, as well as the numerous applications in fundamental physics, chemistry, and so on. So you can see there are lots of applications for lasers.

Now, to learn about lasers and the associated optics, one normally takes a course or gets the information from books and papers, but there's always something that's missing in this kind of learning, and that is the actual seeing of the optical phenomena associated with lasers, and also the related physical optics. So we have tried to fill this need by creating these videotaped demonstrations. In fact, we have about eight hours of them, five hours in optics, and about three hours in laser fundamentals. These taped demonstrations are intended for the individual learner, studies by himself or herself or in small groups, and also, it's intended for the instructor, people who teach lasers and optics and related areas. So we have both of these people in mind when developing these tape demonstrations.

Now, what I'd like to do is tell you a little bit more about these demonstrations. First, let me start with those demonstrations relating to physical optics. First set is related to polarization.

The first one in the area of polarization is associated with a linear polarizer. And here, all we do is show the use of a linear polarizer in determining the state of polarization of a laser. The next one, we look at the rotation of the plane of polarization using a pair of polarizers, and then we go on and illustrate the uses of a quarter-wave plate and a half-wave plate.

And then in number five, we actually take advantage of what we learned about polarization components to demonstrate an optical isolator or an optical diode where light can only go in one direction and not in the other. And then finally, under the area of polarization, we look at the scattered light in a dielectric and we look at it's polarization as a function of the input polarization of the light. Then we go on and look at the behavior of light at dielectric boundaries, for example, a piece of glass.

Here, we look at air-glass boundary first, where we demonstrate the Brewster angle, where for a sudden polarization, there's no reflection at the boundary. And the next one, which is even more fascinating, which is the glass-air boundary, where we can also look at the total internal reflection, as well as the Brewster condition. And finally, here, we look at the phase shift for different polarizations in total internal reflection.

Then we look at two-beam interference where the phenomena are much more dynamic to see. In two-beam interference, we start first with a simple Michelson interferometer using collimated beams and show what fringes look like. And then we switch to diverging beams or spherical beams, and we see rings instead of line fringes. And we look at both the light that's transmitted through the interferometer as well as the light reflected through an interferometer.

Then we get to a fun one here, and that is what happens to the light or where does the light go when we have destructive interference? When we have actually no light coming out of the Michelson interferometer, where does the light go? And in fact, I would like to give you a little preview of this demonstration.

So let's go to the monitor and see this demonstration. Now, as we see on the monitor, we see that Michelson interferometer on the right, and the output of the Michelson's interferometer in the inset above, and as I lean on the table, we see that the light goes all the way from very bright to completely dark or no light at all. Now, just to show that indeed, there is light inside interferometer, what I'm going to do is block one arm with a card, and then if we look in the close up, we see indeed, there is light in interferometer when that arm is blocked.

Now, when I block the other arm, again, we see that indeed, there's light being reflected from each on the front of it. When I take the card off, I can make the light disappear completely, which means I have complete destructive interference. So the whole question is, where does the light go when I have complete destructive interference?

The next demonstration in the area of two-beam interferometry relates to fringe contrast. As we see, we have a number of them. One, we look at the effect of vibrations on fringe contrast, then we look at the effect of different intensities in the two arms of the interferometer and how it relates to fringe contrast, then we look at an interesting one, the effect of different polarizations in the two arms of the interferometer. And finally, here, we look at the fringe contrast as a function of path length difference between the two arms of the interferometer. And as we know, if, indeed, the laser is not single frequency, then the fringe contrast will be very poor for certain path length differences.

Now, in demonstration number 17, we do quite a comprehensive study of fringe contrast or coherence length and its relationship to the spectrum of the laser. Now, I'd like to show you a little bit from this demonstration. As you see on the scope, we show the spectrum of the laser, and this indicates that the laser is oscillating at three frequencies. Below is the Michelson interferometer setup.

And at first I'll start with equal path lengths in the two arms of the interferometer, then we can look at the fringe contrast. Here is a fringe contrast for equal path length. Looks very, very good.

Now what I do, I start to change the length of one of the arms. Here I am round 5 centimeter path length difference, and the fringe contrast looks pretty bad here. 10, close to 10 centimeter path length difference, you can hardly see the fringes.

Again, it's around 12. It's still pretty bad. Then as I go further, this is about 15 centimeters or so, I see the difference contrast comes back. Here I am getting better and better. Here, around about 20 centimeter path length difference or so, the quality of the fringes look as good as they were before.

Now, I'd like to show you other demonstrations that relate to something even more exciting than two-beam interferometer, which is the effect of multiple beam interference. And under multiple beam interference, we have plain mirror cavity. We start with a plain mirror cavity using collimated beams. And again, I would like to show you a little bit from this fascinating demonstration.

On your screen, you see the plane parallel Fabry-Pérot cavity below with a spacing of few millimeters, and right above it, you see the individual beams when the cavity is misaligned. Now, as I start to align the cavity, the beams start to superimpose until I reach the condition when they're all overlapping and we see the interference. And here we are.

In fact, there's practically no light coming out of the interferometer. And as I lean on one of the mirrors, I can bring the transmitted light into maximum and then into a minimum. It's a very, very dramatic demonstration of multiple beam interference.

Now, the next one in the area of multiple beam interference, we look at again a plane mirror cavity with diverging beams this time instead of collimated beams. And here, we see the rings and the bullseye and so on, and also, we look at not just the transmitted beam, but we also look at the reflected beam from this cavity to see what that looks like. And then we switch from plane mirror cavities to curved mirror cavities, and here, we excite lots of transverse modes or radial modes in the cavity. So I'd like, again, to show you just briefly a few of these beautiful transverse modes.

On the screen, you see one of the higher transverse modes as the cavity is being tuned. Here we are. We have a much larger mode. Here is a another one. They're very, very pretty.

And in addition to just looking at the transverse modes, we also in this demonstration, we're going to look at their frequencies. And again, there's a lot to be learned from there. The final one on the multiple beam interference, it relates to the use of a curved mirror cavity as an optical spectrum analyzer, the so-called confocal resonator. So we show you what happens at confocal and what happens when you are below or above confocal condition. And this sort of summarizes the interference demonstrations.

Now, we want to turn to diffraction. And we'll start with Fraunhofer diffraction. Now, when I demonstrate diffraction, I like to be able to change things while I demonstrate. I don't like these static demonstrations.

So what we have here, we have an adjustable slit. We'll start with an adjustable slit diffraction, and we'll show what happens as a function of slit width, then we go and look at what happens when we have two slits, and then when it comes to multiple slits, instead of just showing you just the diffraction pattern of lots of slits, what we do here, we introduce each slit one slit at a time. So we start with 1, 2, 3, 4, 5, 6, 7, and so on, and you'll see how the pattern changes as a function of the number of slits.

Then we quickly look at the diffraction patterns of thin wires and try to relate them to those of narrow slits. Then we go into two-dimensional Fraunhofer diffraction patterns, and we have a variable rectangular aperture. And here, it's very pretty. You look at the diffraction pattern from that.

And then we look at the circular apertures, and finally, we look at the diffraction pattern associated across multiple slits. Essentially, we have here is two Ronchi rulings that we cross, and then we vary the angle between them and look at the pattern. And so after Fraunhofer diffraction, then we show a little bit of Fresnel diffraction.

Now, on the Fresnel diffraction, again, we go back to the adjustable slit, but here, what's interesting about this demonstration, we show you the transition from the Fraunhofer condition to the Fresnel using just that adjustable pair of slits. And it's a fascinating experiment to see how the Maxwell's equations are solved by this slit. And then we end Fresnel diffraction by showing you the pattern that relates to-- the Fresnel pattern that relates to a number of circular apertures, and again, as a function of the curvature of the field incident on the aperture.

And we close our demonstrations in physical optics by looking at the propagation of light in fibers. And as we know today, fibers are very, very important. And what we do here, we show you the behavior of a single-mode fiber first and what happens to the light coming out of the fiber as a function of bending and so on, and then we switch to a multi-mode fiber where the output is no longer a single spot that is consist of different spot, just like in the resonators.

And finally, here, we look at the polarization, the polarization issue in a single-mode fiber and show how touchy it is and how you can change the state of polarization coming out of the fiber by simply just stressing it or just even breathing on it. And this concludes about five hours or so, as I said before, of demonstrations in physical optics. Now, let's look at our demonstrations in laser fundamentals.

The first one in laser fundamentals is just a simple laser. So we start with a simple laser. We show you what a simple laser it looks like, and then we look at the very important, obviously important thing in lasers, and that is the amplifier, the light amplifier, which is the heart of the laser. So what I'd like to do is show you a little bit from this demonstration.

On your screen, we now see the amplifier down below, and we have a laser beam that enters the amplifier from the right and exits on the left, and then it goes through a detector, and above, we have a scope that we monitor the laser intensity on, and also a digital volt meter that, again, monitors the laser intensity. Now, when we turn on the amplifier-- and you can see it nice and bright. We turn on the amplifier, you see that, indeed, we get a 5% increase in the light going through the amplifier. And we do that a few times to convince you that indeed, we are observing gain. And we also check on initial conditions and so on, but this is just, as I say, a glimpse of this experiment.

Now, in the next demonstration, we're going to look at the polarization of laser light. We have two kinds of lasers, one with internal mirrors, and one with the external mirrors. And then after that, we look at the spectrum of the laser light and see whether it's indeed oscillating single frequency, multiple frequency, and so on, and also, the polarization of each of these frequencies that comes out from the laser.

Then we have included an interesting little demonstration here that shows that the light inside a laser cavity is much brighter than the light outside. Most of us who understand the theory of lasers believe this, but there's nothing like demonstrating it and observing it. Then we show a little bit about the optics of laser beams.

We look at the beam coming out straight from the laser, then we spatially filter it, clean it up, and it looks fascinating, that Gaussian distribution, and then we focus it and observe it by looking at the scattered light in water. We change the focal length of lenses and show you a little bit about the shape of the Gaussian spherical beam. And then the next one, in the seventh experiment on the demonstration on the lasers, we look at the transverse modes of a laser. Now, these are not normally observed in commercial lasers, because commercial lasers are not supposed to have transverse modes, but in this case, we've got a laser that by adjusting their mirrors and what have you, we can illustrate these transverse modes, and then I'd like to show you a little bit from this demonstration.

On your scope now, you see on the left, we see a donut mode. And this is different, quite a bit different from the normal single spot that we get from commercial lasers. And in the bottom right-hand corner, I'm adjusting the alignment of this laser to bring in a variety of these very, very pretty transverse modes. Now, in the demonstration, we also look at the spectrum of these modes, not just the shape of them. We also look at the spectrum, and we add a few little more interesting things about such behavior.

Number eight on the lasers is associated with the laser sprectal width. Now, the laser speckle width, the intrinsic laser spectral width is normally not observed because it's very, very narrow, and it's usually corrupted by vibrations or what have you and shaking of the cavity, but here, we do some clever little tricks to give you a feel for, indeed, the very extremely narrow line width that comes out from a laser without the effect of this cavity shaking. The next one, the next demonstration on the reflection back into the laser, this gives us a feel of how lasers misbehave when we reflect the light back into the laser cavity. We show here that you get a lot of frequency instability, as well as amplitude instability when the laser light is reflected back into the cavity.

Then the next demonstrations, we then change from helium neon laser to an argon laser, and in this one, number 10, we show you how powerful even an unfocused beam from an argon laser is just by simply letting it fall on a piece of cardboard and setting it on fire. The next one, we show that an argon laser lays in several wavelengths, and we can, using a grating, we can show that indeed, a laser can oscillate simultaneously at several wavelengths. And here, we look at a method of achieving single frequency behavior in a long argon laser by the use of an intracavity etalon, and then we show what happens if the etalon is adjusted right, and also, what happens when it's not adjusted right.

Then we go to the very colorful laser, which is the tunable dye laser where we can tune the wavelength anywhere from green to red. And I would like to just take a few moments to show you the changing color coming out from this dye laser. So on your screen now, we see that the output from the dye laser now.

We just diffuse it and let it fall on a screen. You can see it's going from green to sort of orange. And if your screen is set right, now it's going to red, and even deep red by simply tuning the dye laser.

And in the last two demonstrations, we use the dye laser to excite atomic sodium. We look at the strong fluorescence, resonant fluorescence from atomic sodium when the dye laser is tuned to it. And in the final one, we look at fluorescence from molecular iodine. Now, in this demonstration, we actually show the incident laser light, the color of the incident laser light, and simultaneously, we show the color of the iodine fluorescence induced by the laser. In some cases, the colors are identical, in some cases, they're not identical at all, and that makes a very, very nice demonstration.

Now, in viewing these demonstrations, you may want to use black and white instead of color because of the limitations in video recording, especially on VHS, you may want to use black and white in certain cases. So what I'd like to do now is illustrate in one of the diffraction experiments, the cross beam across multiple slit diffraction experiment. I'd like to show you how things improve, the viewing improves if we switch to black and white.

Now, on your screen, you see the Fraunhofer diffraction pattern of cross multiple slits or Ronchi rulings. In the left bottom corner, you see me adjusting the orientation of one of the Ronchi rulings with respect to the other one. You can see the pattern, which consists of many, many dots. You see it rotates as I rotate one of the Ronchi rulings.

So now, let's turn off the color and go to black and white. And indeed, you can see the resolution now is higher because the red now doesn't show the bleeding, and then you can see some of the finer spots. Again, let's go back to full color. Here we are, back in full color, and then the switch back to black and white to show the higher resolution. Now, you may want to do that wherever you think you need more resolution to help you observe the effect.

Now in other cases, for example, in the case of where does the light go in destructive interference in a two-beam interferometer, you may wish to use freeze frame if you have that freeze frame capability, and then you can admire the complete darkness of the output, the output of the Michelson interferometer. Now, most of the demonstrations were actually recorded here in the studio on this table using a laser like this. And in fact, this laser, in most cases, and some of the optical components. Few of the other demonstrations, for example, of argon laser and the dye laser, were done in my laboratory at MIT.

And let me remind you of one important thing, that in all these demonstrations, I do not present any theory, nor equations, nor a diagram. I think the setup that I will use in a lot of the demonstration is quite simple to follow, and I describe it very, very slowly. But I do give some references for background reading. In fact, I have listed over here some of them.

In the area of optics, one recommended text is*Introduction to Modern Optics* by Fowles, and another one,*Optics* by Hecht, and of course, there are other ones, and you may have your favorite book on optics, and you can certainly use that to review background material. In the area of lasers, I've selected *Introduction to Optical Electronics* by Yariv. Another one,*Lasers* by Siegman, and *Laser Electronics* by Verdeyen, and finally, a very readable simplified treatment of lasers with the title *Introduction to Lasers & Their Applications* by O'Shea, Callen, and Rhodes. And as I mentioned before, I'll mention some background reading if you need to connect the background reading with the demonstrations.

Now, I'd like to turn to some hints for people who are going to be using or viewing these tapes. Now, for the individual, or maybe in small groups, I think what you want to do first is to review the material so that you appreciate the demonstrations a little bit more, and then I'd like you to answer some of the questions that I leave unanswered or the question I pose in the demonstrations. And finally, I'd like you to go back and reexamine the background material, and hopefully, you'll get more out of these demonstration this way.

Now, for the instructor, of course, we all know that instructors already know their background material, so you don't need to review that, but what I would like you to do before showing these demonstrations in class is look at these demonstrations, select appropriate sections, and then only show these appropriate sections in class as you discuss the theory or whatever the background that you give the students. And I think in this way, it will come at a very opportune moment. Finally, I think in some cases, you may want to turn off the audio and substitute your own voice, describing the effects, because in some of the cases, the demonstrations are elaborate and take a while, and if you don't have that much time in class, then there's no reason why you can't turn off the audio and describe it yourself, and then you can make the experiment, the demonstration seem much shorter.

As I mentioned earlier, we have eight hours of videotaped demonstrations. It certainly wouldn't have been possible if it wasn't for the able contributions of two of my graduate students, Stephen Smith and Farhad Zarinetchi. In addition, I'd like to give credit to the variable CES video staff for developing these demonstrations with us. As you can imagine, it's not like your normal video program where you're only recording people talking.

And finally, I'd like to thank all my students over the years, both in regular MIT classes, as well as in the summer session, all those students who ask good questions, because it's these questions that really encouraged us to develop these video demonstrations. And in closing, before I let you go and view these demonstrations, I'd like to say that I hope you'll enjoy looking at them and learn from them, and more important, I hope that they will increase your excitement and enthusiasm for the laser and optics field.

Now, these demonstrations are by no means perfect. I'm sure there are lots of improvements that can be made. But I think that they illustrate what they're supposed to illustrate quite clearly. And finally, after viewing these demonstrations, if you have any comments or some suggestions for other demonstrations that we may have left out, we certainly would be grateful if you would contact us and let us know.