Optical Methods for Solid and Fluid Mechanics
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Lecture - 17
Particle Image Velocimetry II

Hello and welcome back. To rewind we were discussing particle image velocimetry I had shown you this particular diagram and I have told you that there are these different aspects of particle image velocimetry which depends on a case-to-case basis on how you will choose the right optical elements the right light source, the right tracer particles etcetera and the right camera also and even how the process of imaging and the image processing also. So, we will go one by one through all these different aspects of particular image velocimetry.

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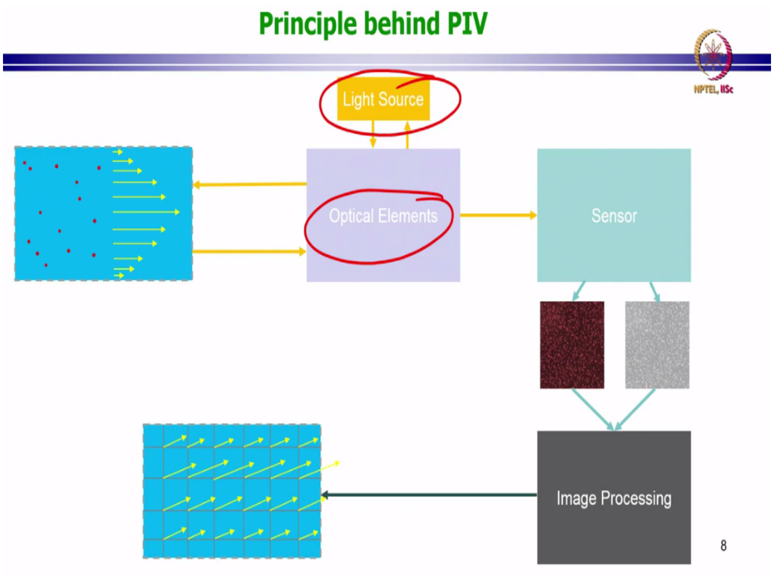

Last time we also already talked about tracer particles, we have understood how theoretically tracer particles need to be chosen, what are the theoretical considerations and then we looked also at the practical consideration. So, we just talked about some of the realistic choices that are there those choices are indicative and not the only choice. So, you should be careful and when you are doing your own experiment you have to make a choice based on your particular experiments and the particular conditions that are prevailing there.

So, having discussed that next topic I would like to discuss is the topic of the light source and then I will discuss the topic of the optical elements. Now in the optical elements case there are actually a number of different possibilities each depending upon the particular case, but what I will restrict myself to is the conventional particle image velocimetry setup where cylindrical lenses are used to create light sheets.

So, we will look at some of those calculations because that is very traditional and a very often used situation. So let us go back to our writing pad and we talk about the light source.

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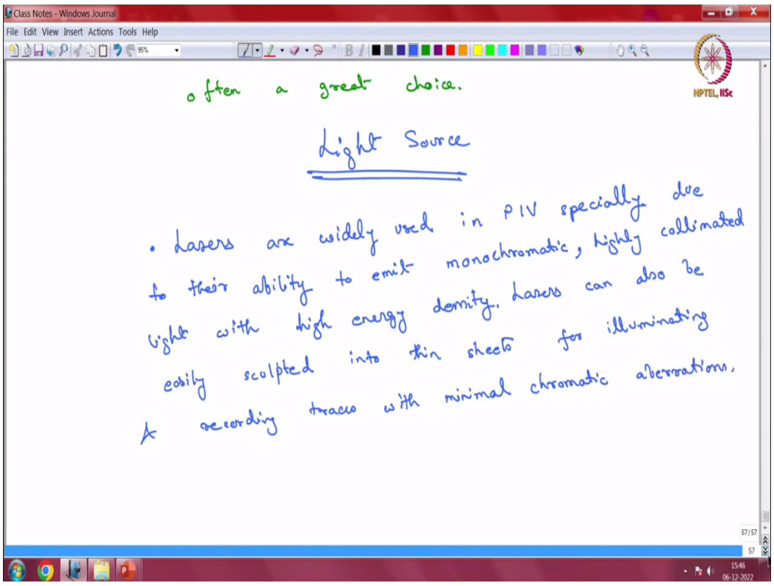

So, we have talked about the tracer and now we are going to talk about the right light source. Now lasers are very widely used in PIV there is a good number of reasons for that and the reasons are especially due to their ability I have the first thing that comes into your mind is the monochromaticity of lasers. So, emit monochromatic highly collimated light with high energy density.

And because of this nature lasers can also be easily sculpted into thin sheets for illuminating and recording tracers with minimal chromatic aberrations.

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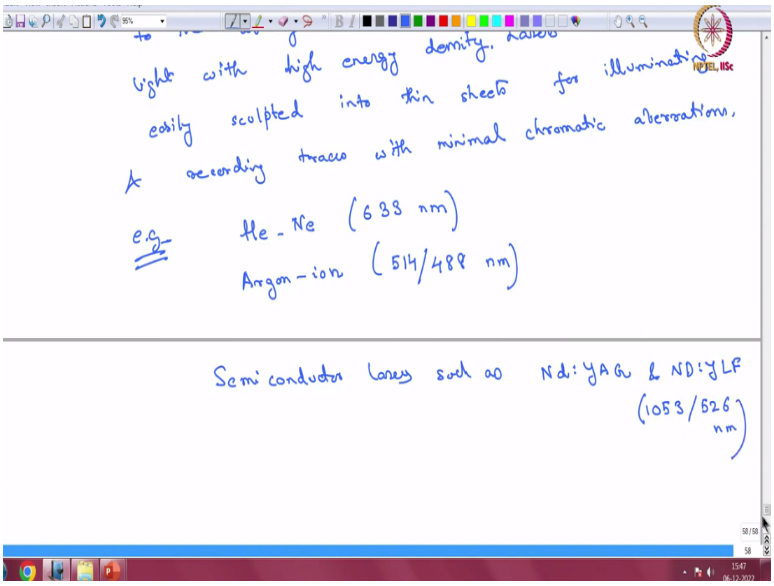

Now example again, for example, a very often used laser is the helium neon laser which is usually operates at 633 nanometers. We also have argon ion lasers which are often used. Here the wavelength is either a 514 or 488 nanometers. Semiconductor lasers are also quite popular such as Nd YAG and ND YLF. Lasers are also quite popular this, for example, comes usually in two different wavelengths 1053 and 526.

The natural wavelength is higher one and then you can do a frequency doubling and end up with 526 nanometer wavelength also. Now lasers are not a necessary precondition. Lasers as I said they are widely used because of their high energy density and by which I mean practical concentration behind that is if you take an image with a very low exposure time laser will give you enough light in order to be able to record good signals.

Whereas if you have a white light source it might not have a high energy density so if you start taking very low exposure images then you may not have good image quality. So, that is why the difference is, but white light sources can also be used there is nothing against it as such it again depends on a situational, it is very situational.

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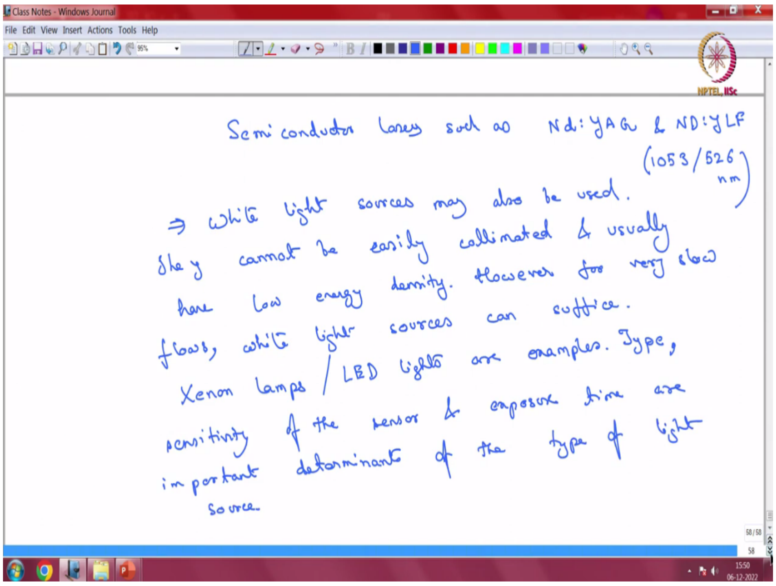

So, I am going to mark this that white light sources may also be used and they cannot be easily collimated and usually have low energy density however for very slow flows white light sources can suffice. Xenon lamps or LED lights are examples. LEDs though they can come in specific colors. So, then it is not exactly a white light source sometimes to have a white light source different LEDs are put together.

But even otherwise if you are using a colored LED you will get a set of specific wavelengths. So, now to decide all this you look at the type sensitivity of the sensor and exposure time are important determinants of the type of light source. So, again we are not giving you absolute principles here, we are just indicating to you what are the typical cases.

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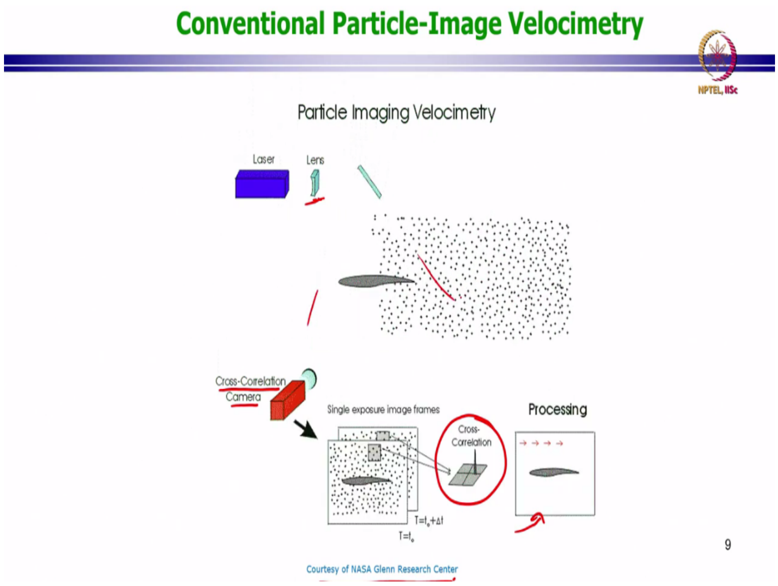

Now, if we go back to this particular image you had seen. You see there is a cylindrical lens that is being used and the beam of light that is coming and is becoming a sheet right here. So, you can see the laser sheet approximately in this location. So, for that we have to use cylindrical lenses to create laser sheets. So, with regards to the two optical elements I am not going to discuss in detail all possible optical elements because that will be too exhaustive for this course.

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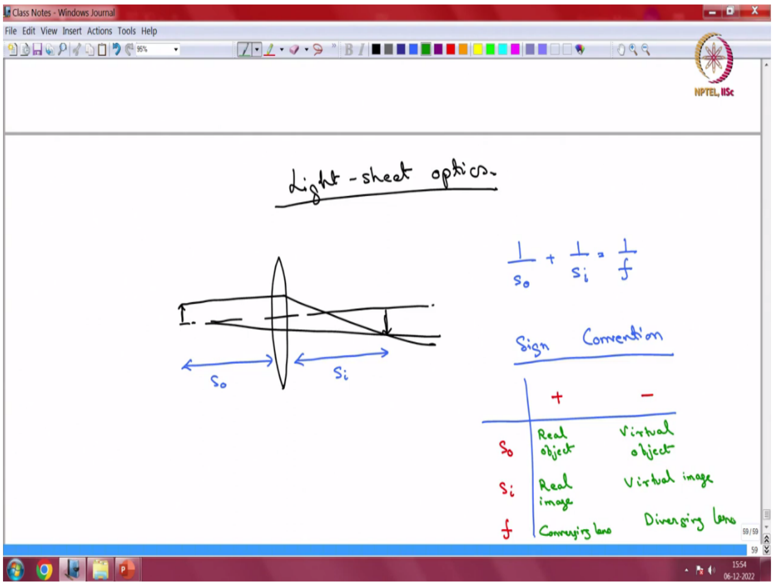

But we are going to discuss this particular issue of light sheet optics. Now, I will ask you to look up simple geometric optics if you are not familiar with it, but in simple geometric optics we discuss how lenses form images. Lenses can be thick lenses they can be thin lenses. For thin lenses there is a very famous equation that relates the image distance, the object distance and the focal length of the lens.

So, for example, if you have an object here which is forming an image somewhere and let us say this distance is s 0 and this is let us say s i then this famous equation is valid for thin lenses which is 1 by s 0 and 1 by s i is equal to 1 by f; f is the focal length of the lens and here the sign convention is important I am going to adopt a sign convention of a particular book, different books can have different sign conventions.

So, you are free to pick from the right one if you choose a different sign convention you will just have to worry about the proper equation the pluses and the minuses so just be careful with it. So, in this particular sign convention we say something is positive so let us say s we have these three quantities here s 0 s i and f s 0 being the object distance s i is the image distance and f is the focal length of the lens.

And if you have a real object we associate a positive sign with it, if you have a virtual object we associate a negative sign with it. Similarly, for s i it is positive, it is a real image and it is a virtual image it is negative and f is positive it is a converging lens and f is negative it is a diverging lens. Now, if you wish to refer to a book I will give you a particular reference.

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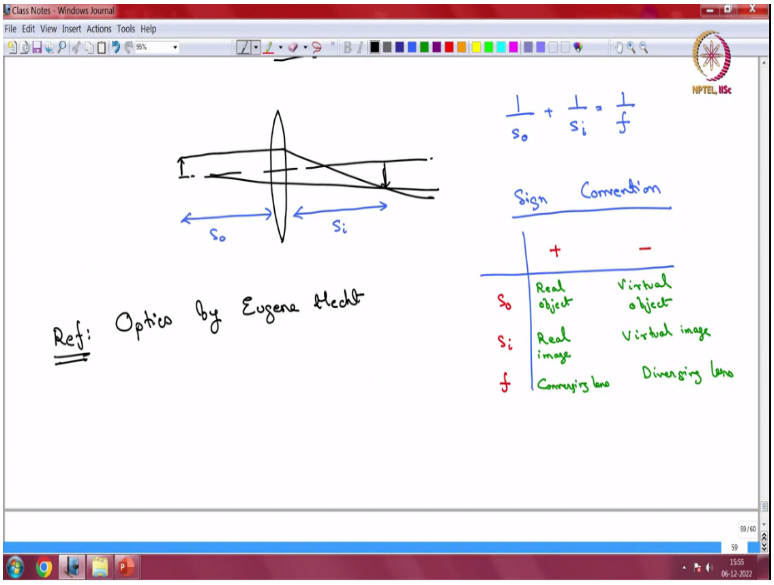

And you can look up other references reference text too, but this is a book that I used. So, I will just give you the name of the book this is called optics and the author is Eugene Hecht and this is I believe the copy I have is by Pearson Education and you should look up the current publisher of this book. So, this is a book you can refer to or you can find any other book as I said different books have different sign conventions for discussing geometric optics.

So, you should just be careful if you use a different book make sure that you know the proper sign convention that they are using. Now the important thing to discuss here is a two lens combination. Obviously there are multiple lens combinations so you can go on by creating a more complicated setup by just putting lenses together. Obviously the most simplest complex system in this case is a two lens system.

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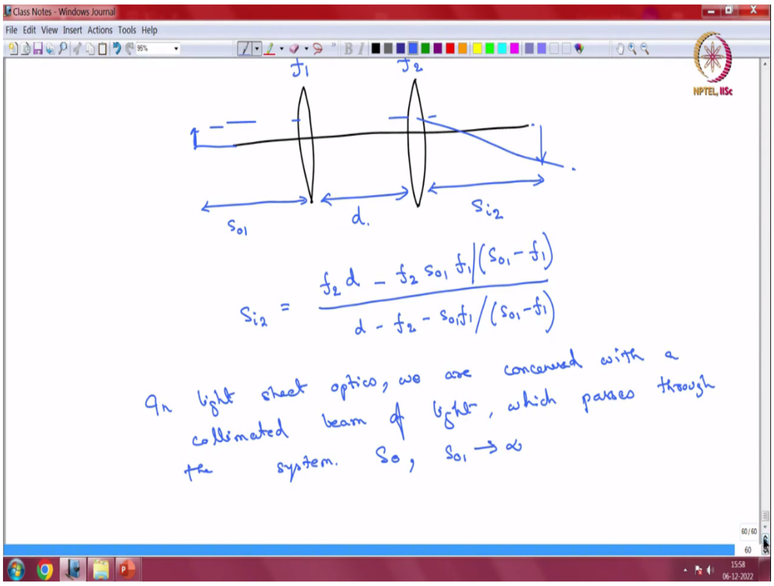

So, we will discuss what happens if you have two lenses. So, let us say your two lenses which are separated by a distance d and let us say the focal length of the first one is given by f 1 focal length of the second lens is given by f 2 and let us say you have an object and the distance of the object from the first lens is s o 1 and this object finally forms an image somewhere in the system.

And we will call this particular distance from the second line some s i 2. In such a case geometric optics and I am stating the result without any proof and again you are free to look up the book. This s i 2 is given by this equation f 2 d – f 2 s o 1 f 1 divided by s o 1 – f 1 divided by d – f 2 – s. So, this above equation it tells you how an object of a finite size located at s o 1 will be imaged in the optical system and where this image will be produced.

So, this allows you to calculate that. Now what is interesting in light sheet optics is that the first lens is usually converging lens whereas the second lens is a cylindrical lens. So, that is what makes things interesting so we will look at it ad in light sheet optics the light that enters from the left is usually a collimated laser beam. So, in light sheet optics we are concerned with a collimated beam of light which is a laser and which passes through the system.

So, my s o 1 is basically infinity and wherever the image forms when a collimated light enters that distance you can calculate now with this above formula and that distance is also called the back focal plane. So, the back focal plane is where the image is formed when you have a collimated light entry.

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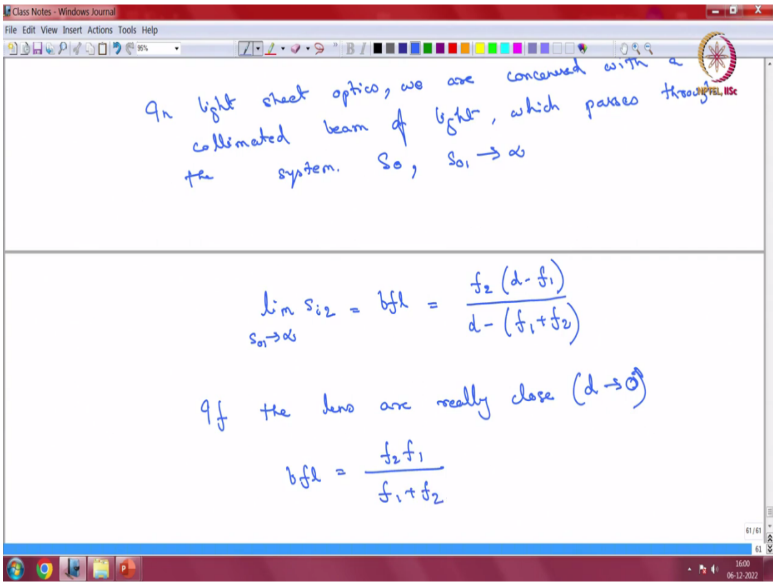

So, I can say in mathematical terms that my s i 2 and the limit of s 0 1 becoming infinity is also called the back focal plane and this distance if you simplify using the above equation this simplifies down to this equation now. I urge you to verify this by yourself and make sure that I am using it correctly. Now if the lens is very thin sorry if the lenses are really close sorry not the thin these are already thin lenses.

If the lenses are really close which implies that is d tends to 0 then my back focal plane equation becomes even simpler and reduces to f 2 f 1 by f 1 + f 2 and with this the best way to understand light sheet optics is through a sample calculation.

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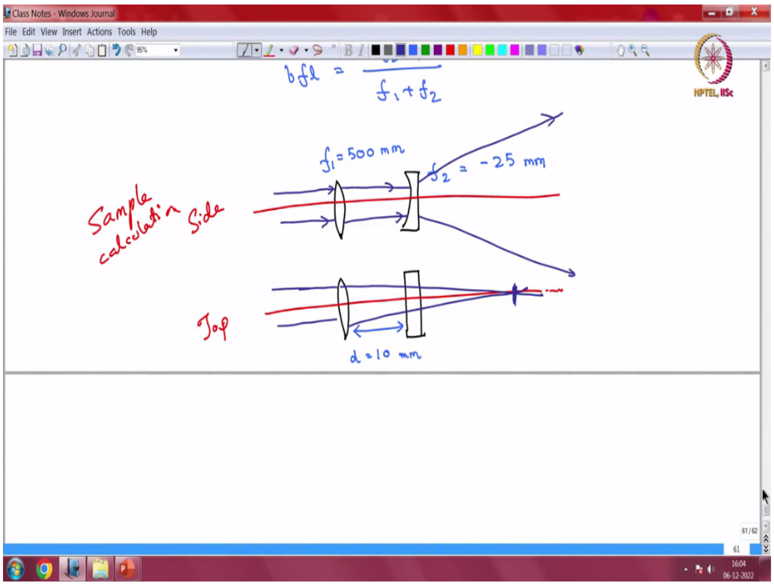

So, let us say you have I am going to draw first the side view of this and then the top view sorry top view. So, let us say we have a spherical lens coupled with a cylindrical lens. So, we have a spherical lens which in the top and the side view looks the same and then on this side you have a cylindrical lens. So, in one of the views your cylindrical nature can be seen and in the other one all you have is a rectangular slab.

So, it does not do anything to the light and let us say that this distance is given to us. So, d is given to us as 10 mm the first lens is a spherical lens the second lens is a cylindrical lens and the focal lengths are provided to you. So, your first focal length is 500 millimeter I am sorry and the second lens f 2 is - 25 mm. Now you see the advantage of having set up the proper signs convention here.

We have already set up the sign convention so we know what a negative sign for f means, but interestingly in the second case here this is in the top view the effective focal length is 0. So, so you have to be careful in interpreting the number. Now both these side and the top views I want to reiterate this show you the same physical setup along two different axis and because of the cylindrical lens the image or the figure I have drawn for the cylindrical lens they are different.

So, now we can do our calculation and so the whole idea is that there is I need a different color to say let us see. So, we have let us say a light coming in a collimated light which comes in. This collimated light goes into my cylindrical lens as a result of the cylindrical lens this light diverges like this in one of the axis whereas in the other one the light and the other axis the light only sees the spherical lens and basically it just ends up converging somewhere on this point.

So, this is maybe the location of the back focal plane. So if you had to do a quick calculation about the back focal planes etcetera I encourage you to try and do this yourself right now because we have given you the equations. So, I will give you a minute to think about the particular problem and the question that we are going to ask you is give us the geometrical parameters of the slide sheet.

So, I am just going to stop for a second here and let you do the calculation and pick up right after that.