Optical Methods for Solid and Fluid Mechanics
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Lecture - 08
Light Matter Interaction I

Okay welcome back everyone. So, just to recap what we are doing last time we were looking at images and what we realize is an image can be read is essentially a matrix and with the appropriate software you can read the matrix and then you can see how the values are distributed. Now in an RGB image we said it is basically it is a m cross n into 3 matrix where m cross n is the size and pixels for the particular image.

Whereas in image for experiments in science we often use monochromatic images because the information in the other two channels is often redundant. This is usually because of the way we are measuring something and the object of interest can often be just measured in one single image in a monochrome sense, but that this is not an absolute absolutism in any sense. So, there can be instances where the colors might be important.

But usually you will see that some of the images that we use for example in particle image velocimetry or particle tracking velocimetry we do not need the different colors. So, we deal with monochrome images there. There are examples, for example, when you will encounter the concept of using polarized light to visualize stresses in solids which will happen in the second part of this course.

You will see that the colors might become important over there. So, with that we had the discussion and then we also realized that once you read this matrix into a software when you read the image in a matrix format. You can now do a lot of different mathematical operations which become possible for you. The particular operation we looked at a few different operations.

And where we stopped last time was we were discussing the idea of convolution. Now discuss the idea of convolution we first introduced convolution as a generic idea. Over here these are the formulas for your continuous functions and this is for the discrete case then what

we started doing is we started looking at convolutions for vectors obviously because we want to look at convolution of matrices.

So, on the way we simplified our problem and looked at vector convolution and we saw how to do the do the calculation in that particular case.

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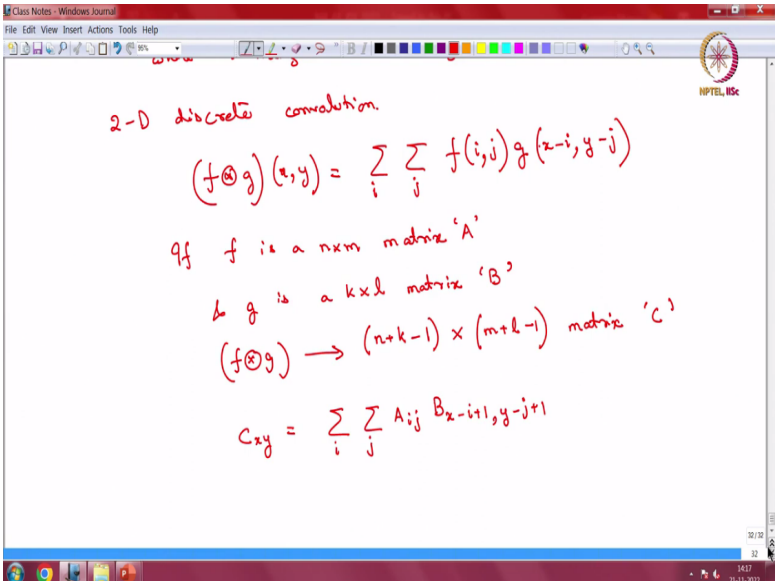

And then this is exactly where we stopped, we are looking at 2d discrete convolutions and this is the general formula for a 2d discrete convolution. Now we as we suggested earlier we are interested in matrices because we are interested in images. So, if f now is n cross m matrix and we will call this matrix let us say A and g is k into l matrix B then your f convolved with g is basically another matrix.

But this matrix now has n + k - 1 into m + l - 1 terms and so and matrix and we will call this matrix let us say C. Now in order to calculate the individual terms of the matrix we are going to say let us say C x y is one term of the matrix then what you have to do to in order to evaluate C x y is sum this over i and j just like last time, but in this case you have A i j and this other matrix you will have x - i + 1 this is y - minus j + 1.

So, this is how you do the operation for this particular case. So, now that you are earned with this knowledge you can just go ahead and start using different convolutions or different matrices and convolve your image with them. Different matrices will have different effects. Here in this particular course we are not again going to go into a whole lot of depth in this particular topic because we are not going to encounter convolutions much at all.

But I will give you one particular example and this example I think is a very common example when people discuss convolution of images and this is; so let us say you have a large image and you want to do a sort of a mean over few pixels.

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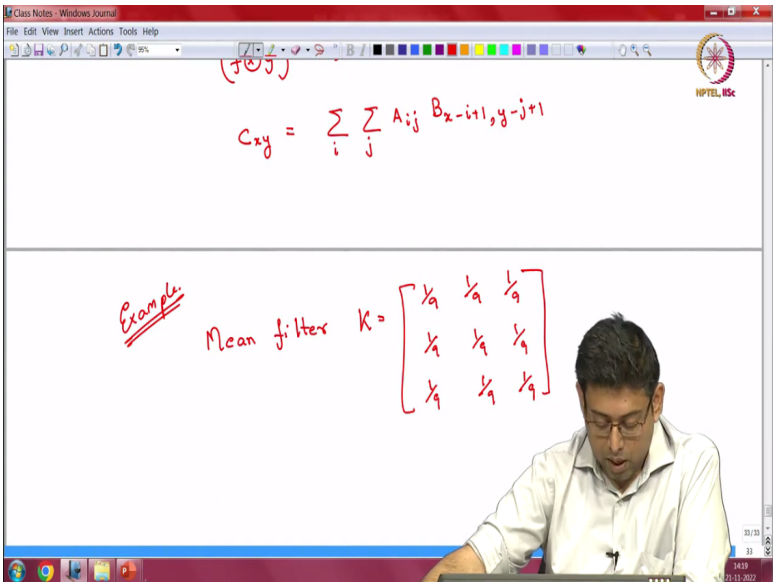

So, I will just do an example and this example is often called the mean filter. So, let us say this is a matrix K and this matrix is defined as you know all the terms in this matrix are equally distributed. So, there are 9 terms 3 cross 3 matrix and all with weightage is distributed equally amongst all these different entries. So, this is what the mean filter looks like.

And then you can do a convolution over with another image that you might have and then you might want to see what the effect of that is. So, what I have done is I have already done this operation once in Matlab and I will show you what I have done. So, I hope you remember this image that I had showed you before and here I am going to redo the operations just for some of the simple operations just for your sake.

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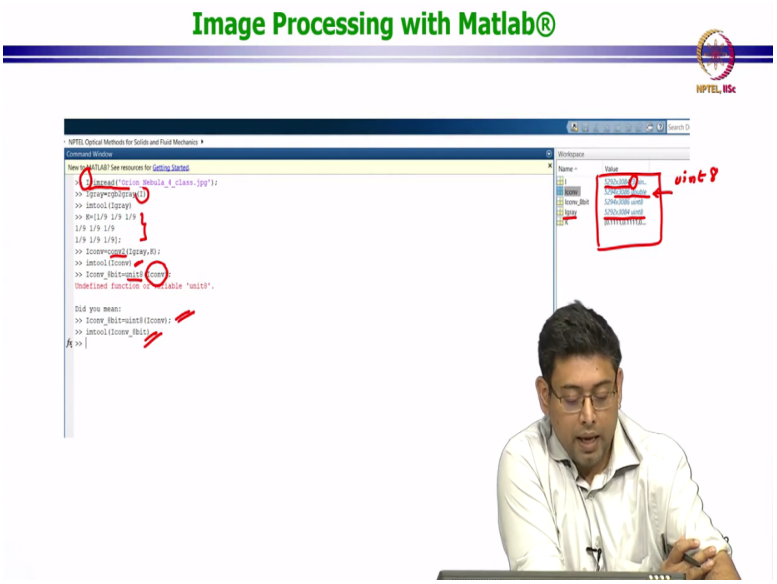

So, for example, the first line I use the command I am read and I read this image into a matrix I and this I as you can see on my right hand side this is my right hand side which gives you the workspace in this case you can see this is m into n into 3 matrix and there is a let something written here u i n and actually it is not fully complete its uint 8. So, this image what it means it is an 8-bit image.

So, a pixel can take a maximum value of 255 and a minimum value of 0 in this case. Now, this is actually a color image as you can see from this entry of 3 right here and so then we go ahead and use the command RGB to gray to convert this matrix I into a grayscale image. So, now my when I do this I get a matrix as an output called I gray which is now just an m cross n matrix.

Now I am doing an im tool using the command im tool this will pop up this image in and render this image in a box for you then I will go ahead and I define my K matrix here which I showed you right in the previous when I was writing down in my notes. Then I define a convolved matrix which is a convolution of so the function that is used here is conv2 and I do a convolution of I gray and k.

And then I pop up this image I have this image rendered as well using my we call im tool. Now in order to do this so this does not work very well because the problem of Iconv is when you do the convolution is that you end up getting a matrix which has entries which are where the entries are double. So, this the this will not work when it comes to images because all the matrices must be similarly formatted.

So, they must be formatted as uint 8 matrices. So, here I use the command uint8 to force this matrix which is the convolution of the two matrices I and I gray and k to now become an 8 bit matrix. So, now when I do that I can have both of these displayed I actually here I made a mistake of using not saying uint8 and instead unit 8. So, this mistake was detected and I was not able to define it so I defined it here properly.

So, after doing all these commands I will end up with the output right now. So, I am using my imtool command here to display both the matrices. The matrix I gray which is the grayscale version of the original matrix and then the convolved ones too.

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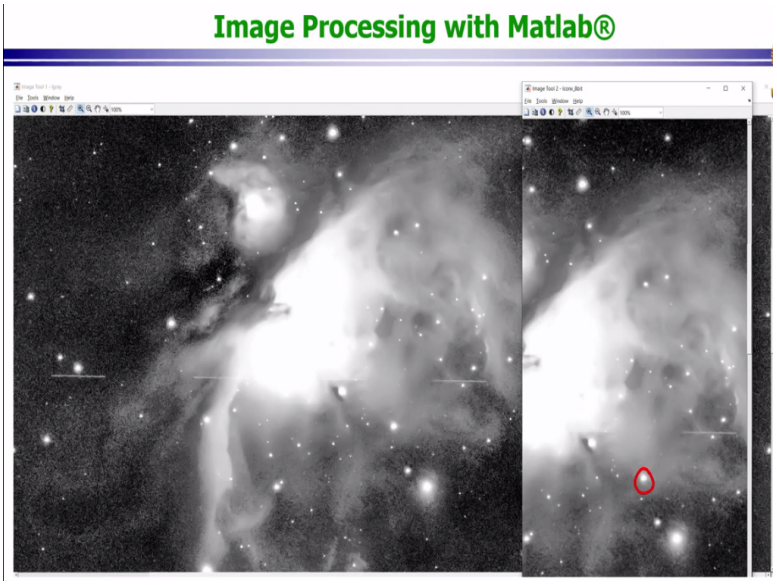

So, what I have done here is I have taken these two images and I have put them side by side. Now you will see that it is very difficult to tell what the big difference here is, but this image if you look around let us say here around this region. You will see that this image is a bit more smoothed out than this particular one. So, the smoothing is a little bit better and that is because the k matrix that we are using the for the convolution is smoothing out this image a little bit.

Now this mean filter can also blur very sharp images. So, sometimes it may be desirable sometimes it may not be desirable. So, whether this kind of convolution is even desirable or not is something you have to determine on a case-to-case basis. Here my use of the mean filter is essentially leading to a little bit of smoothing of the two images whereas in the in other cases where there might be very sharp images it might also lead to blurring.

So, with that we will end our discussion on this image processing. Now I must say that any discussion on image processing can actually be very detailed because it depends on what you really want to do as an output you can just keep on going. So, in our case our focus is going to be more on analysis of these images for getting velocity fields. So, the entire intent is to make sure we get the velocity fields from particle tracking or particle image velocimetry.

So, we are going to focus on those image processing aspects rather than the other ones. So, depending on what you want you might want to choose that kind of a content from somewhere else if you want to look into more details of just general image processing. For example edge detection could be one which we are not going to go into. So, what we are going to do now is going to discuss.

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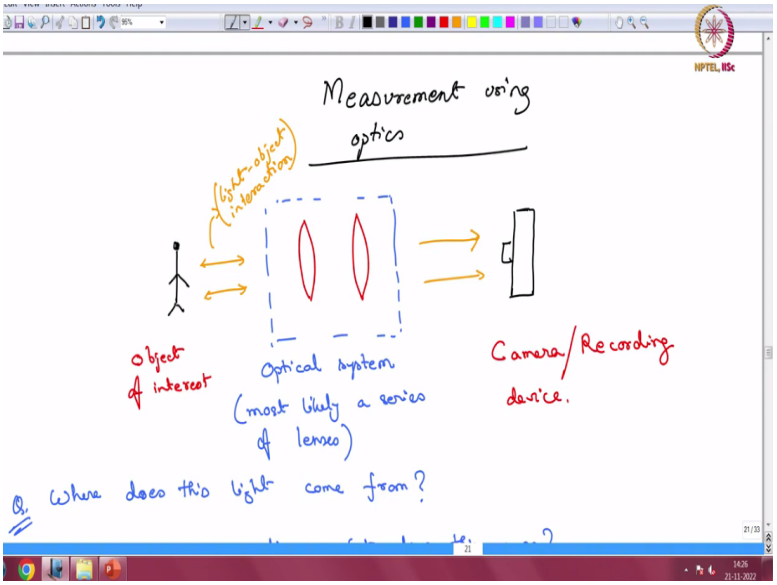

So, I think I made a drawing here somewhere where we are discussing measurement systems. We discussed this oversimplification of the entire process where we said that one part of the entire image processing system or our case consists of light matter interaction. So, we have an object of interest we have some matter here I have just used a stick drawing to draw a person.

But this is just representative of some matter and then you have light falling onto this and then coming back from it and then it goes through an optical system and finally is recorded by a camera. So, this particular portion the light object interaction I am going to discuss a little bit about it. Now the topic of light matter interaction is quite involved and it can

basically take several lectures if you are interested in knowing all the details about the interaction portion.

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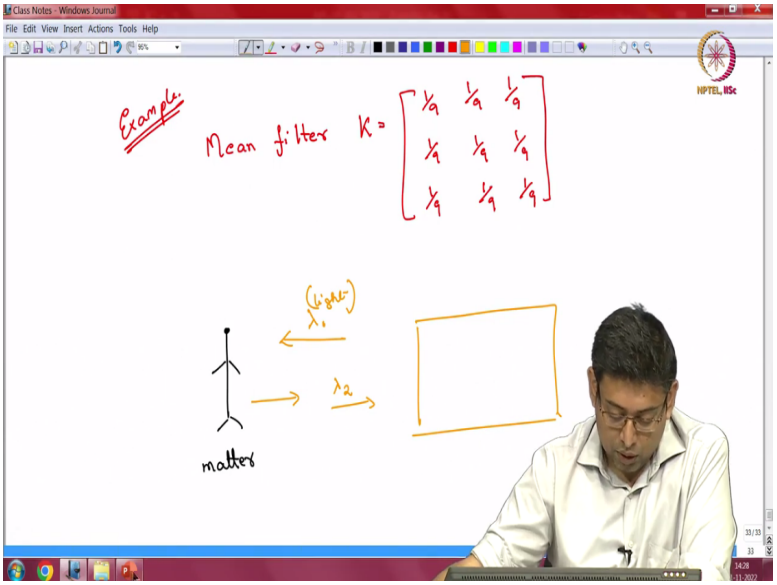

Because you have some matter which I am representing by a stick drawing here and then you have light falling on it. So, you have some light of some wavelength lambda falling on this. So, this is my light and then this is going to interact with it somehow how we are going to look into and then it is going to go back in your optical system. So, this is the light that returns to your optical system. So, you have some optical system here and this is the light that is returning back.

So, this could be a lambda wavelength and this could be another wavelength that is returning back. So, this wavelength now has to be processed by an optical system and finally it gets recorded on your camera. Now the question is what is this light that is falling whether you need an external source of light that needs to fall on this or not and if yes then what is this lambda 1 and then the other question is what is this lambda 2.

So, a full discussion of how this happens needs to go into a lot of details about let us say (()) (14:34) scattering resonant and non-resonant varieties which we will not do in this particular course, but rather I realize that one easy way of highlighting all this is through examples. So, what we are going to do is I have chosen for you certain examples and in that example I have just chosen some videos of some experiments. **(Video Starts Here: 14:58)**

And so I will briefly describe what we are going to see in this particular video. So you have a fluid here obviously right so this is some fluid and you can see this fluid is colorless. Now, if this rod rotates this fluid is going to move, but if the fluid is colorless and transparent how do you see the motion you cannot it is transparent and that is why you will not be able to see anything.

So, in order to visualize this in this particular case what we are going to do is you can see this needle right here and we are going to deposit a dye and this dye is going to be of a very bright color and once the dye is deposited and this rod will start to move and then the fluid will also start to move. The movement of the fluid will redistribute the dye in this volume and that is something that you can actually start to see and that will give you an idea of the fluid flow in the bulk also.

So, with that prelude let us now just look at this particular video. So, the dye has been deposited now the rod was started. Now the dye is redistributed and I hope you can see these different profiles these fronts that are developing for example here. So, now here by looking at this dye which is of a different color than your medium you are able to visualize the fluid flow to some degree. So, I will play this video one more time for your benefit.

So, I hope you could see that the fluid it seems as if there is some vertical motion right and that you can see from the movement of the dye and but you can only get slightly qualitative information in this particular case not very quantitative ones. So, now I am going to show you the same situation so it is the same experimental setup with a small thing that has been now changed.

So, instead of a dye what we do is now this is just let me explain this is the rod the rest half of the rod you cannot see because it is taken with a slightly different camera and this is going to now move there is a laser that is on that you cannot see and that laser actually is a green laser and its coming out fanning out like this and its, illuminating these tracer particles. So, these are all silica tracer particles we have seen this type of video before.

But I just wanted to show it for completeness. So, now as I play this video you will see the particles move. This is a video played in a lot more slow motion than the video you saw before. So, you can actually see the motion of all the particles where you can actually get a

pretty good idea of the bulk motion right here. So, in these two cases these are the same two experimental setups.

Here what type of light you are using and in one case here we are using just normal light of the room to illuminate the system or you can use a halogen lamp that is on the side to illuminate it and that itself is more than enough, but in this other case we needed a laser to illuminate the particles and there is a reason for that. So, that is where the whole idea of light matter interaction sort of comes in and that is why it is important to understand what your optical system needs to process and how. **(Video End Here: 19:38)**

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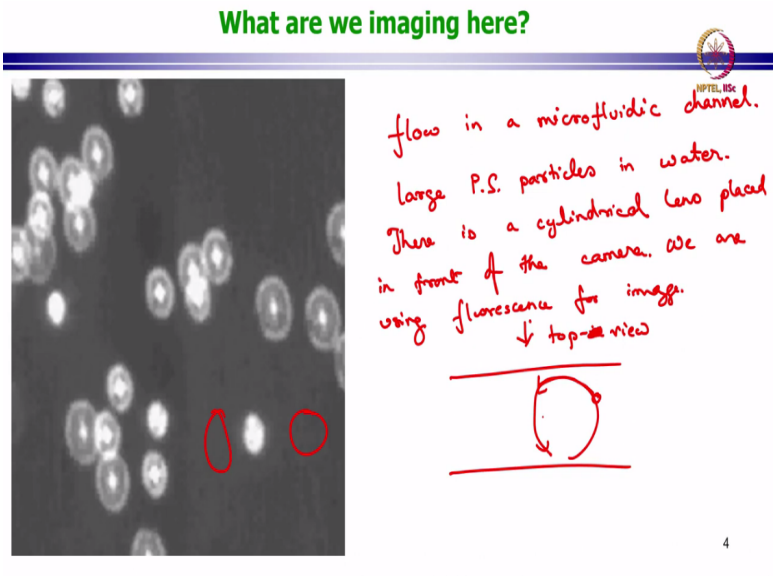

So, now I am going to show you a slightly different type of imaging this is done in an optical microscope, this is flow in a microfluidic channel. The microfluidic device is not visible. These are large polystyrene particles for which I will just write P S the P S meaning polystyrene particles which are neutrally buoyant in the water. There is a cylindrical lens placed in front of the of the camera and we are using fluorescence for imaging.

So these particles are fluorescent which means when a certain wavelength of light is illuminated on it, it absorbs that particular wavelength and emits another different type of wavelength. So, this is not your simple light scattering in that case. So, it is a sort of a most complicated interaction of matter with light and so I am just going to play this short video and I am going to explain what you are seeing.

So, actually what is there is there is a vortex type of flow and you are looking from it from the top. So, that view is a top view this is top. So, this particle is approaching your focal plane and then going out of it. So, you can see the size of this particles changing as it approaches your focal plane and then goes away from it the particles are bright, the sizes are changing and they are all (()) (21:56).

So, it is not a circle these are elliptical. The elliptical nature comes because of the use of the cylindrical lens right in front of the camera and that is done deliberately. I realize I did not give the citation of this. So, this comes from one of my previous works maybe in the next class I will give the citation and from this you can do a particle tracking and you can actually get a profile of this three-dimensional flow in this particular case.

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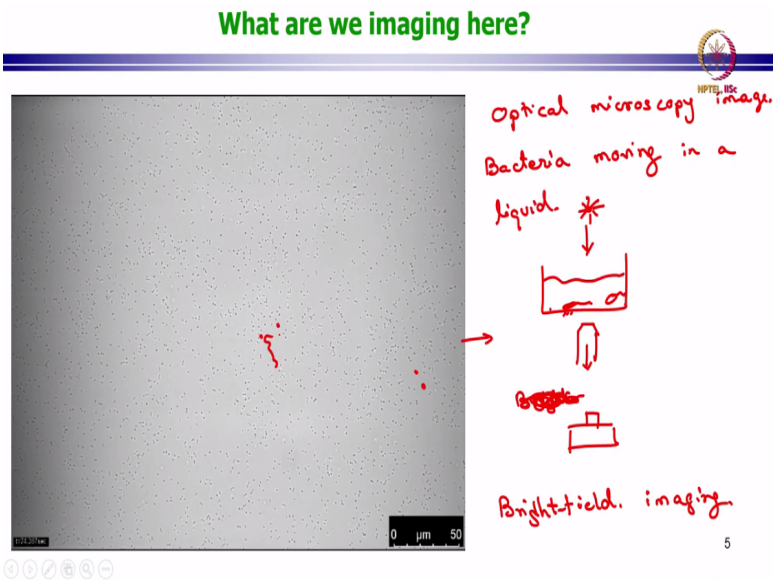

And here I am going to show you a very different type of video again what you are seeing is optical microscopy image. These are bacteria moving in a liquid colorless liquid all again and this is your; so it is you are looking so you have all these bacterias and you are looking from the bottom. So, their lens is at the bottom and we are seeing a lot of these bacteria attached to this.

So, these are visible as these black dots and this is done through imaging process called as; so here there is a source of light that is at the top and the light just comes and it passes through the system and is collected by your microscope lens and then finally it ends up in a camera. So, it is also called a bright field imaging I am sorry my pen is acting a bit weird so this is called bright field imaging which is just an optical microscopy method.

So, I am going to play this video and I hope you will be able to see. So, I hope you can see this the bacteria are very light in nature and you can probably see a lot of bacteria moving around very fast in the background. The black dots are stationary these dots are stationary and in these spaces you can probably see a lot of these bacteria which are moving around. So, a very different type of image from the previous cases although the previous case also utilized optical microscope of a very similar type.

So, these all come from very similar experimental setups, but some of the light matter interaction in this case, for example, fluorescence was being used and in this case it was not being used and it leads to very different type of images in the two cases.

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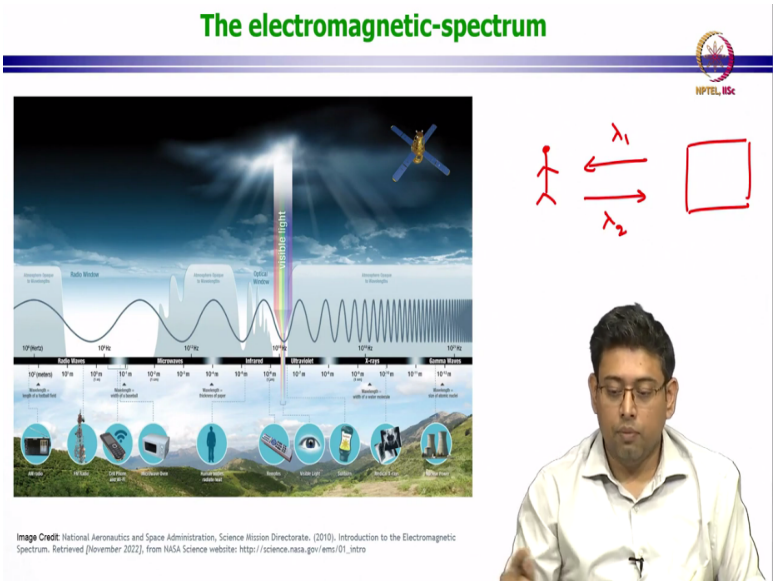

Now all this is because of the nature of this interaction and as I said you have some light falling and some light being going away into the optical system that we have. Now when it comes to light; light is nothing but a part of the electromagnetic I mean visible light which we call it is nothing, but a part of the electromagnetic spectrum. So, this is an image that I have taken from this website right here.

And it shows very beautifully the distribution of the different types of waves electromagnetic, different wavelengths of the electromagnetic spectrum. On the left you have radio waves then your microwaves then you have the infrared and then here you have the visible spectrum right here then it goes into shorter and shorter ones towards the right where you have the ultraviolet x-ray and the gamma waves.

So, most of our realistic experiments they all end up using the visible light or a portion of the visible light. So, you are not going to use the entirety of this visible light spectrum. You are probably going to try and limit yourself to some portion of this visible light spectrum. In certain cases you might want to use as thin a wavelength distribution as possible that for example happens with a laser.

So, when you illuminate your material with a laser you are using basically a very narrow or almost like a single a single wavelength of light that you are using to illuminate that particular material. So, if you are using a green laser you are probably using something like 532 nanometer of wavelength to eliminate it. So, what we are going to do now is it is easier to understand all this if we move into the lab where we are going to do a small lab session.

And I am just going to give you a prelude of what the lab session is going to be about. So, now you see that we are going to use an electromagnetic spectrum or part of the electromagnetic spectrum for illumination and we are going to illustrate all this.

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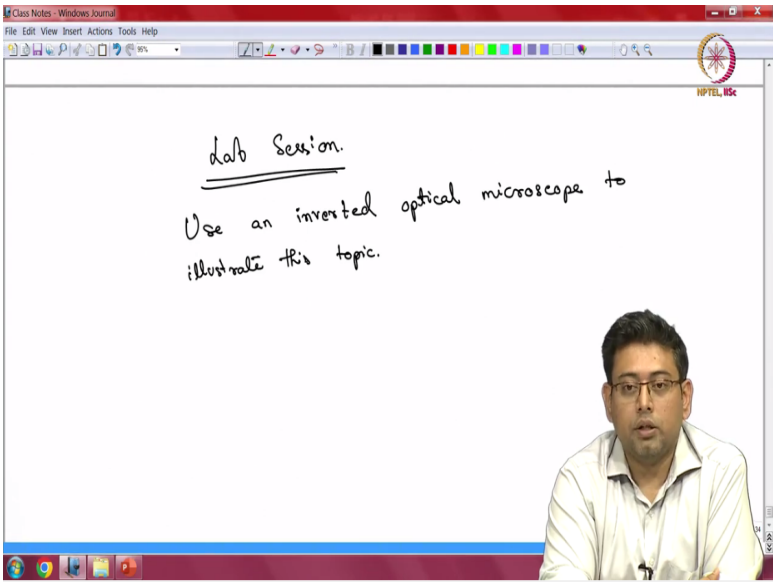

So, next what we will have is a lab session we will use an inverted optical microscope to illustrate this topic which is of light and matter interaction and how it results in different types of images. So, what we will have is we will use lights of different types first, for example, we might use white light which has a certain set of wavelengths in it or a certain range of wavelengths that it covers to eliminate our object of interest.

Then we will try to narrow it down using what is called as filter cubes and that helps us to use narrower bands of light to eliminate our material and all this will result in different types of images. So, as we change the optical methodology, the type of images that we will start getting is going to be slightly different. So, what we will do now is we will stop here and we will move into the lab.

And then I will follow it up later on with a slightly more better explanation of what you probably saw. So, we will stop here today.