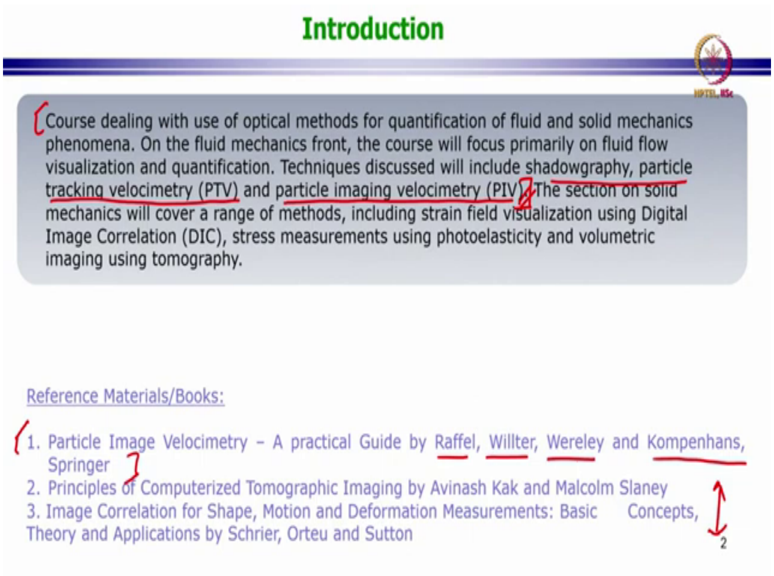
Optical Methods for Solid and Fluid Mechanics
Prof. Aloke Kumar
Department of Mechanical Engineering
Indian Institute of Science – Bangalore

Lecture – 01
Introduction and Historical Perspective

Hello and welcome, this is going to be a class on optical methods for solid and fluid mechanics. This course will be taught by two professors myself and Professor Kaushik Vishwanathan. I am Aloke Kumar. I am an associate professor in the Department of Mechanical Engineering. My colleague Kaushik, he is in the same department. So, let us see what this course is going to be all about.

(Refer Slide Time: 00:30)



So, now, if I had to introduce the course I could simplistically state that this course will deal with the use of optical methods for quantification of fluid and solid mechanical phenomena. On the fluid mechanics front, the cores will focus primarily on fluid flow, visualization and quantification. Techniques that we will discuss will include shadowgraphy, particle tracking velocimetry, particle image velocimetry.

The second section of this course which is going to be taught by my colleague that is going to focus on the solid mechanics portion and will cover a range of experimental methods, including strain field visualization like DIC, which is stands for which is short form for digital image correlation and other techniques, such as photoelasticity. So, what you can see here is this course is going to be.

So, I am going to be teaching till here which is the first portion of the course so, from here onwards to here. And as you can see from some of the names if you are familiar with particle image velocimetry, particle tracking velocimetry these are names of all experimental techniques. So, you can get a feel of the course that this course is going to primarily focus on explaining the experimental techniques used for quantification of fluid flow.

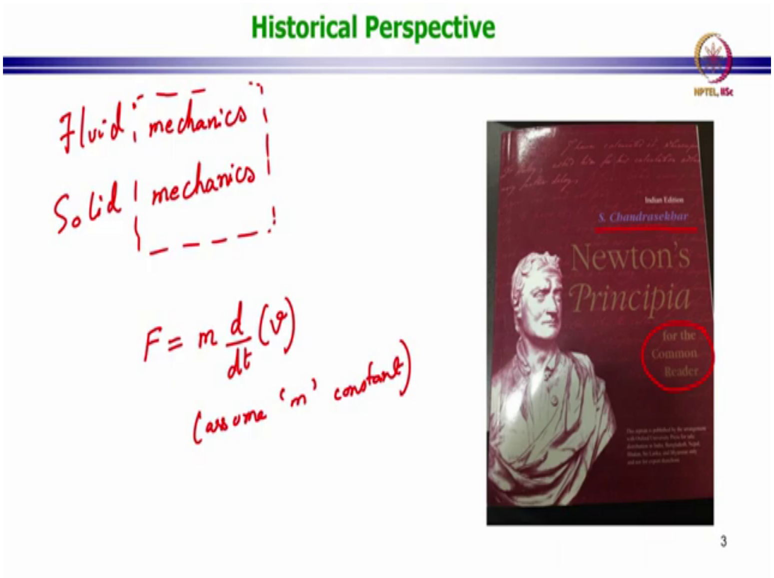
And then we are but before, even that we are also going to learn some of the preliminary requirements that are needed to understand and perform some of these experiments. The reference materials that are required for this course I have also pointed at out here. There so one book, for example, particle image velocimetry it is a very nice book which gives you a nice practical guide.

It is also titled a practical guide but this goes through a lot of details about experimental handling. As well as all the mathematical preliminaries that are required to understand particle image velocimetry technique. And this book is written by Raphael, Willter, Wereley and Kompenhans, it is a springer publication Now, these are the last names of the authors, Rafael, Willter and this is one of the books that we are going to refer.

And these other two books these are going to be for the second portion of the class, so which is again, as I said, will be covered by my colleague, Kaushik. So, these are the particle image velocimetry happens to be one of the most widely used experimental techniques in this area. And hence the book that I have proposed or as a reference material deals with just that this we are going to use a number of different books as we go along.

And I will try to give you as many references as I can along the way. So, this is just the beginning and for every small section there might be some other book that I might ask you to. If you are interested in looking it up in that detail, you can look up. So, this is the introduction of this course and as you can see that I focused on the two words in the beginning, the quantification of fluid and solid mechanics phenomena right here. So, these, are our operative words, fluid and solid mechanics.

(Refer Slide Time: 04:20)



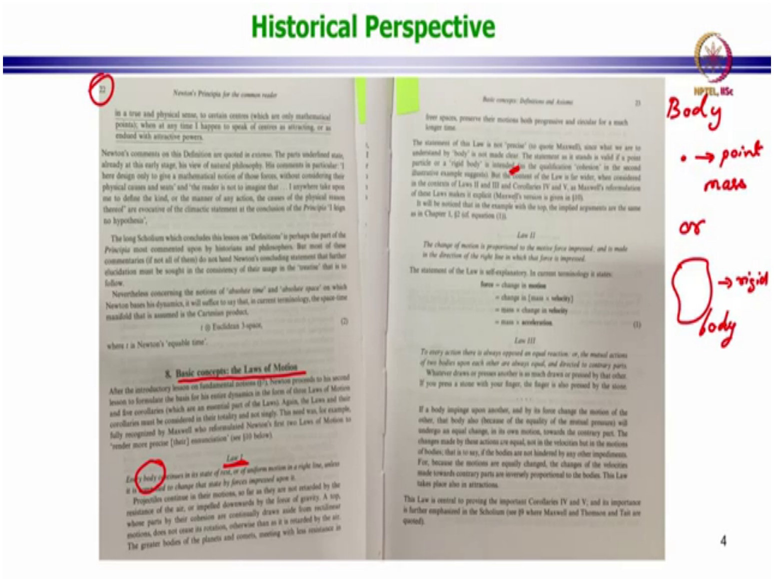
So, if I had to write, I just so, let us say I am just going to quickly write this fluid mechanics and solid mechanics. So, what is common to the both of these obviously is the word mechanics and it does not come here by any mistake. It is a very important that these are both of these are offshoots of the overall topic of mechanics which is a very important part of mechanical engineering curricula or any physical sciences curricula.

So, since we have already stated that the basis of both of these is in mechanics. Let us start with the fundamental laws of mechanics that we are familiar with and which happens to be the Newton's Laws of Motion. So, now, with regards to Newton's Laws, Newton wrote gave a lot of wrote down a lot, his understanding and his propositions in the very famous book called The Principia.

It is difficult to read the principia because it is not in the kind of language we are used to now. So, here I am proposing a book if you have time you can take a look at it. This book is actually, written by Subramanian Chandrasekhar, the famous Nobel Laureate. And he goes he simplifies down Newton's principia for the common reader. It is a very nicely written book and it explains much of the details of Newton's work very nicely.

And elegantly and has a lot of Subramaniams' or notes on those topics. So, now so, basically, what we want to look at is this very famous equation which in the case of constant mass so, here assume mass is constant. So, this is the fundamental topic of making the one of the fundamental equations that we use in mechanics. So, let us try to take a look back at what Newton had said originally for this.

(Refer Slide Time: 06:49)



So, this is a portion from the book. This is page 22 and here I am going to read out from what Subramanian has written here. So, this is he is talking about the basic concepts, the laws of motion and I will just read out some of this. And so, he says I am going to quote here after the introductory lesson of fundamental notions Newton proceeds to his second lesson, to formulate the basis of his entire dynamics in the form of three laws of motion and five corollaries.

In brackets, he says which are essential parts of the laws. Again, the laws and their corollaries can must be considered in the totality and not singly. This need, for example, was, for example, fully recognized by Maxwell who reformulated Newton's first laws, two laws of motion to render more precise their enunciation. In fact, Maxwell wrote a very famous book called Matter on Motion.

If I am not mistaken and that clarifies a lot of things about mechanics. Now, let us get to the important thing here which is the first law which we want to read one more time. I am sure you are all very familiar with this law. It is quite famous and something people read while they are in school but still there is something important that we need to consider. So, here, for example, it says everybody continues in it is state of rest or of uniform motion in a right line unless it is compelled to change that state by force is impressed upon it.

And then these are Subramaniam's notes be underneath it project. So, he says, projectiles continue in their motions so far as they are not retired it by the resistance of the air or impel downwards by the force of gravity, a top whose part parts by their cohesion are continually drawn aside from reptilian emotions does not seize, it is rotation. Otherwise, than as it is by the air, the greater bodies of the planets and comets meeting with less resistance in freer space.

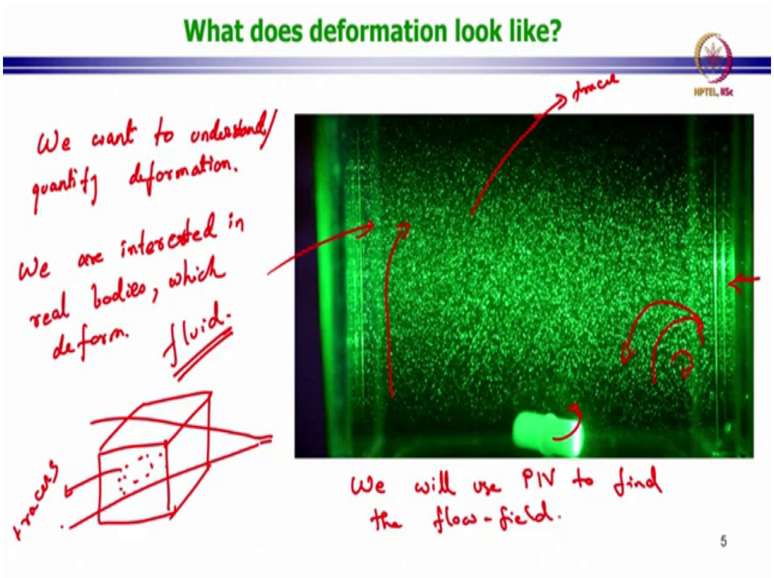
So, it goes to the next page which I have here preserves the emotions, both progressive and circular for much longer time. Now, there is an important, thing here which is this term called body that Newton uses and here Subramaniam makes a very nice point and he says that the statement of the law is not precise. And he is quoting Maxwell here says, what are we to understand by body is not made clear.

The statement as it stands is valid if a point particle or a rigid body is intended as far but the content of the so, we will just stop here. So, the point is that this word called body here in the first law. This body means a point mass so, it either refers to a point mass or a rigid body. So, if you are taking a finite body then it is a rigid body. And the rigid body is a body which has infinite resistance to deformation and basically does not deform.

So, a rigid body does not deform. So that is the critical portion idea here. So, Newton's laws when we look back at it basically is intended for either a point mass or a rigid body. Now, this is where we come in we are actually, interested in understanding real bodies, bodies that are not rigid. So, these real bodies they deform and we are interested in understanding deformation.

So, both in solid and fluid mechanics, we encounter deformation of bodies and that is what we are interested in and not just interested in seeing the deformation. We are interested in quantifying it and understanding.

(Refer Slide Time: 10:44)



So, I am just going to make this point here again we want to understand slash quantify deformation. Actually, in this particular course we will not go so much in the details of understanding but rather we will confine ourselves to the quantification of deformation. Because that is what we are more interested in this course is designed to be an experimental course or a prime introductory experimental course in understanding deformation.

So, we are interested in and real bodies which deform. So, Newton's laws are still applicable here but for that we have to, it is going to now start being valid for point masses. And then, if you want to understand the behaviour of a real body then you have to start from these point masses and build up from there in order to understand deformation. So, here what I am going to show you is a fluid mechanical deformation.

So, what we have is this is a fluid here that we will see and the experiment that we are showing you here. It is actually, carried out and cubicle box like this, where there is a laser that is being shown. It is a green laser and the laser is illuminating, this is a laser sheet which is illuminating the box and there are tracer particles in the fluid. So, these are tracer particles tracers.

I just deleted that so, small tracer particles are in the fluid and what is going to happen is there is this top here which is going to rotate. So, this is as this rotates this there is flow that is going to happen in the system. **(Video Starts: 12:57)** So, **(Video Ends: 13:06)** I hope you were able to see that I will play this video one more time for you. And I want you now to do something for me which is when you look at this video.

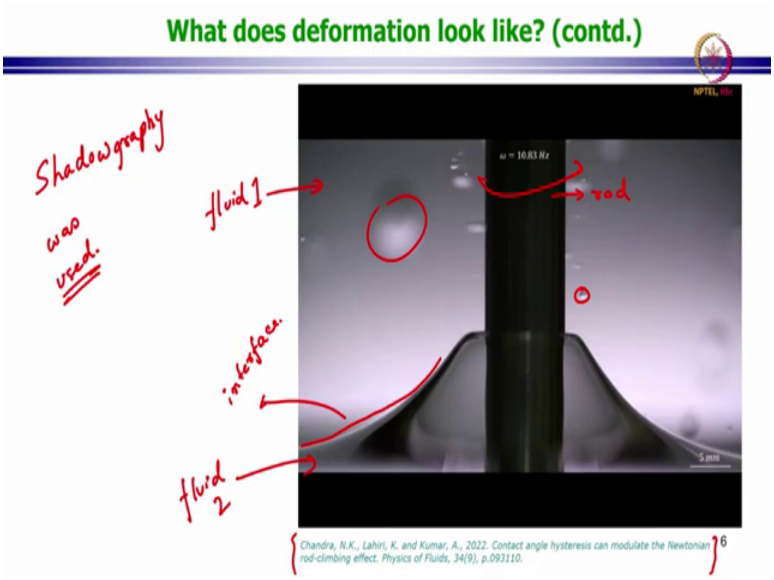
What I would like you to do is? Try to look at the particles which are moving. These are all traces, these small small, small, green dots. These are looking green because there is a green laser that is coming from the side. And these are these small things these are your tracer particles. Now, the fluid is moving, so, the entire body is deforming in this particular case. And from the motion of these tracer particles, you should be able to visualize some of the flow that is happening.

So, I want you to take a look at this video one more time and try to see if you can understand how the flow field looks like. **(Video Starts: 13:49) (Video Ends: 13:59)** So now, if you were careful enough, you could have seen that the flow is moving up here. There is this motion that is there I think this is the correct direction. Let me we can recheck if that is the correct direction or not. But if you see these portions I mean you can see flow all around.

But along the wall here this flow which is moving up on this section you have this eddy type of situation right here. Let us just see if the arrows are correct and of course, you can now see flow at every different, all the different points. **(Video Starts: 14:32)** My arrows were in the wrong direction this is the flow is actually in this direction. **(Video Ends: 14:41)** So, this is this gives you an idea of a deformation of a fluid system.

And you can already see why this course has been named as such. You are using light in this case there is a laser that is coming and we are trying to understand flow behaviour, whereas we are visualizing flow. As well as we will see how this kind of an image or video actually, helps us quantify the flow field also. So, this this is specifically meant for this course this particular video we will use we will later use PIV to find the flow field quantify the flow field actually.

So, this is one type of deformation let me show you a slightly different type of deformation now. **(Video Starts: 15:34) (Video Ends: 15:36)**
(Refer Slide Time: 15:36)



This is so now, here what I am going to show you in this particular video. As you can see, this is also a video that is taken using this it involves fluids. Obviously, so, there is a fluid 1 here and there is another fluid here, this is fluid 2. Fluid 1 is lighter than the fluid sorry fluid one is lighter than fluid 2 so, it is up and this is the interface. So, this is your interface and this video is taken using a principle called shadowgraphy.

Shadowgraphy was used and I will play this video for you and I will just quickly tell you what is happening there is this rod here. So, this black object is the rod and it is moving at it is going to rotate and the angular velocity is given here is and I will play this video for you. And let us see how what happens. **(Video Starts: 16:49) (Video Ends: 17:45)** So, the video has now ended.

So, I am going to play it again for you and I want you to try and observe a couple of things. One is in the last video you were able to see the flow field inside this time we do not have any tracer particles. So, the question is are you able to understand there is obviously some sort of a flow field here on the side but can you visualize the flow field? And then you can see the deformation of this meniscus.

So, this is the deformation of the meniscus and what happens is the meniscus rises upwards and then later on it breaks. This breakage actually, later on even causes the appearance of these small these droplets, here and it sort of becomes an immersion on the upper liquid. So, this video, while it does involve fluid flow and deformation is a very different video from the previous one.

So, I will play this one more time for you. **(Video Starts: 18:43) (Video Ends: 19:39)** So, the video has ended again. So, you see the video the fluid 1 in the beginning was very clear. There is nothing there is no dust particles or tracers or anything in there. It is very difficult to see how the fluid is actually, moving. Although you probably have a feel that there is a fluid moving.

Later on, as this droplets form the upper fluid becomes a bit unclean or in some sense, as has other phases in it and their motion gives you an idea of how the fluid is actually moving. So, this is another type of experimental technique and we will talk about this also when we talk about experimental methods by the way. If you want to read more about this paper or this type of motion, you can refer to our paper which was published in 2022.

And it discusses the physics behind this phenomena it is called the rod climbing effect and this is for a Newtonian, two Newtonian fluids. So, this gives you some idea of of deformation in fluids.

(Refer Slide Time: 20:48)

We now, move on to deformation in solids so, we have solids and solids also undergo the formation. Now, what will happen is we will as you will see the deformation in fluids is rather large. And I use that word very qualitatively here and please excuse me for that but I know what I am I will quantify that later but right now just excuse me for that use light use of that word.

But the flow fields or the flow it usually fluids is extremely large, whereas solids undergo deformation many a times most regular solids. The deformation is small. Again, I am as I said I am deliberately using a slightly qualitative word called small here, saying that the deformations are small. I will explain that also later but first we want to understand deformation in solids and this is an example of photoelastic measurement.

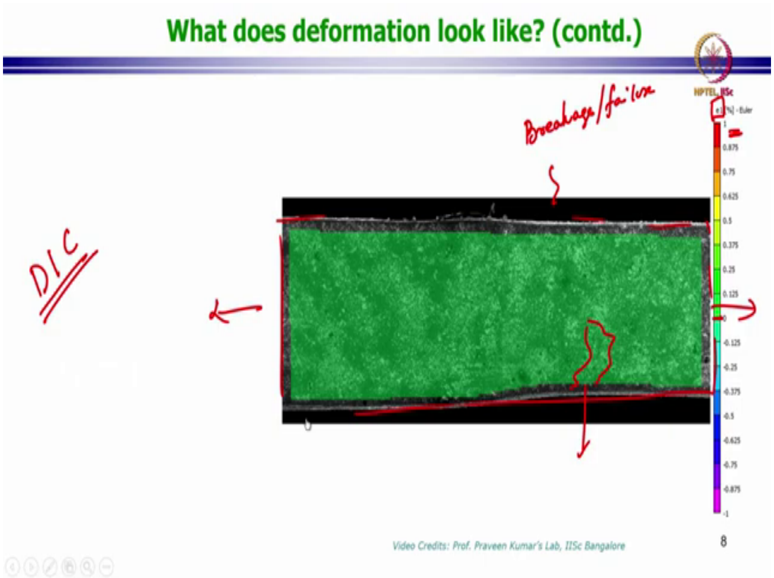
And what you have here, there is this rectangular bar that you see and there is a hole here in the middle of this bar. And this is held here by clamps and these clamps are pulling it so, this entire thing is in tension. And there are special glasses here. You can probably see my reflection, so, this is me taking the photograph and you can see my reflection in this glass. These are special types of glass which is allowing you to visualize in some sense.

These fringe patterns that you see right here these are your stress fields. These are not quantitative but it does not tell you how much what is the value of the stress? Where there is red? And what is the value of the stress? Where it is yellow? But it is giving you some sort of a qualitative idea that here there are stresses are different than the places in, let us say, the red places are of different stress than the regions of yellow colour.

So, this is another reflection by the way in the mirror. This is somebody else helping me out in the lab. This is from a picture when I took in when I was in Canada. So, this is photoelastic measurement and these are all small deformation problems that we look at. So, this is this gives you an example of that here obviously, the deformation is so small that you will not be able to see it with your naked eye.

And this is obviously probably gives you an idea of what I meant by saying, small and large in fluids. The deformation is large enough that you can visually see it.

(Refer Slide Time: 20:48)



Here the deformation is going to be small enough for you to see for a small enough for you to not be able to see. This is video that I am going to play this exemplifies a an experimental technique called DIC which is digital image correlation. I will quickly, explain what you are going to see here. We have again a bar that you in the background, this bar is being pulled again in the two directions and it is undergoing a tensile test.

And it is actually, going to break from somewhere here it is going to fail breakage slash failure will occur somewhere here in the middle. What you are seeing here there is a green patch overlaid on our actual experimental image. And this green patch is actually, showing a strain value and this is one of the principal strains you can see green here it stands for 0 this colour bar is given on the side.

So, you can sort of see the value right now everything is static, so, the entire field is green. There is no strain value associated with the system. By the way I would like to thank Praveen Kumar's lab at material science department at IISc Bangalore for this particular video. So, let us just go ahead and play it and see what happens.**(Video Starts: 25:00) (Video Ends: 25:08)** So, you can see there is some kind of a fracture **(()) (25:12)** happening here.

This is a breakage that is happening there. This time the strains were large enough for you to be able to see unlike the photoelasticity example that I showed you before, you can see the things moving. But they are not moving very far away from each other. From than the original locations and these are the different places are undergoing different strains you can see the change in the values of this bar graph.

So, the colour values have now changed and now, the red is 27 value here. So, I will play this video again and you will see that this bar graph on the colour graph on this my right hand side that also changes in numbers, so, the numbers associated with the different colours they start changing. **(Video Starts: 25:54) (Video Ends: 26:02)** So, I hope that gives you a rather good overview of what deformation looks like.

That was the whole point of it and I tried to show you deformation different examples of deformation. In the first case, we saw the first case we saw some fluid flow. This video and then the next one we saw deformation of a meniscus. The fluid flow was difficult to visualize at two different techniques are employed and then I showed you some deformation happening in a in a solid body using photoelastic measurement.

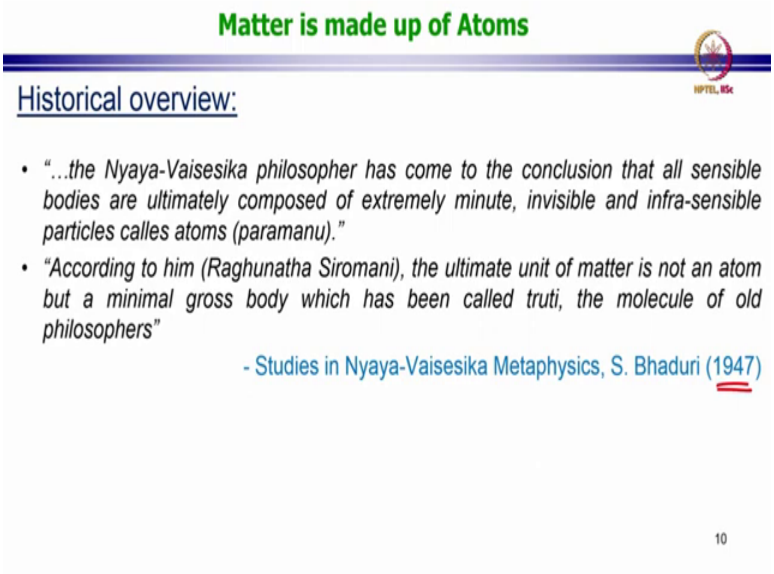
This is also a different experimental technique and then here we showed failure using of an exemplified technique called DIC. So, these are all different videos.

(Refer Slide Time: 26:56)

And this gives you an idea of what type, of course material you are going to see in this particular class. This is just an introductory lecture, so, I just want to give you overview of the entire thing and in this particular module and I hope some of you are thinking why do materials deform? I mean at Newton's time he has clearly intended to take a rigid body and after now we clearly see that real bodies do deform.

So, what is new? Why do we understand why what is deform? Well, there is reason why bodies deform is goes back to why what actually forms the basis of matter.

(Refer Slide Time: 27:43)



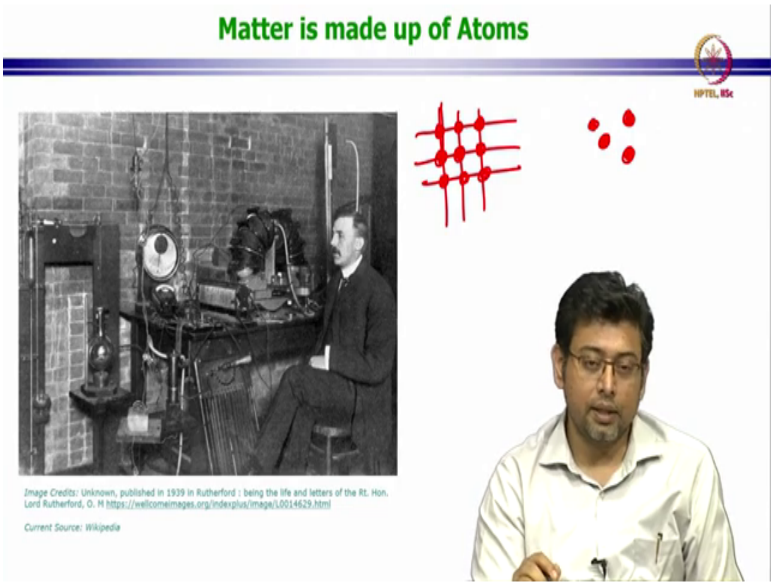
And here I would like to involve a historical overview here. And we know that matter is now made of atoms and but the idea of atoms and molecules has been hypothesized for a very very long time. And for example, in India there was this famous school of thought called the Nyaya Vaisesika, school of thought. And this school of thought had thought about this particular problem as to the composition of matter.

And they realize that matter is actually, made out of very minuscule building blocks so as to say. So, I am going to quote from a particular book. I am going to give you the reference also. And it says the Nyaya Vaisesika philosopher has come to the conclusion that all sensible bodies are ultimately composed of extremely minute invisible and infrasensible particles called parmanu, atoms.

And it this book later on so, I will also tell you which book it is? It is studies, Nyaya Vaisesika metaphysics written by S. Bhaduri, it is a pretty old book 1947 is the publication date. And here it says according to him the ultimate unit of matter is not an atom but a minimal gross body which has been called the truti the molecule of old philosopher. So, the understanding that atoms and molecules make up matter is was already there for a very, very long time.

And then Nyaya Vaisesika school is ancient it is very, very old and it is interesting that they came up with this. Obviously, as science progress and technology progressed, we gained better and better understanding of what these atoms actually look like? What are they really indivisible or there is more to that? And obviously, in the last 150 years or 200 years, we have taken massive leaps in our understanding of the atom itself.

(Refer Slide Time: 29:45)



And I am just going to quickly show you this photograph. This is Rutherford pictured I believe in 1905 I have taken this from Wikipedia. But the original source of this is this particular book, The Life and letters of Lord Rutherford. And his experiments and obviously many of his other great scientists. They proved that matter is made out of small individual particles called atoms and they realize what it is made out of.

There is a nucleus there is electron rotating around. Now, in matter atoms and molecules can be arranged in different fashion. For example, you can have a lattice structure and you can have atoms arranged in lattices in a crystal structure. So, you can have a lattice structure and you can have your atoms placed at different locations. That is what usually happens in solids or you can have matter just atoms bouncing against each other in no particular order.

And that is what happens for your fluids, liquids and gases. So, deformation of matter is basically a rearrangement of atoms at the molecular scale. To understand deformation, you actually, have to understand why that molecule or atom displaced. And what is causing it? And how they are located in the very beginning? And what is the new state? In this particular, course we are not going to look at the molecular nature of matter.

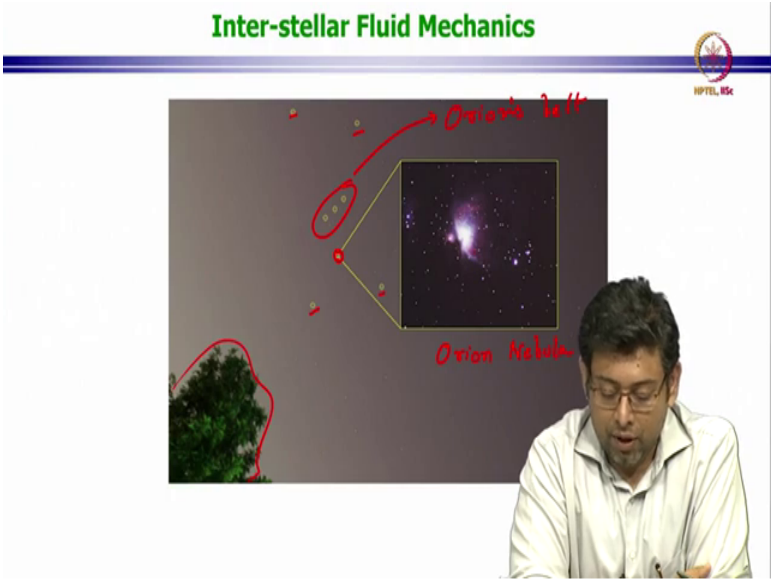
I mean or rather we are not trying to understand how the molecules themselves rearrange. But we are going to look at a more macroscopic picture of the same thing. And the microscopic picture is going to help us out in understanding. The overall deformation and the quantification of that itself will be very very enlightening. So, this is just for our own sake that the matter is made out of atoms and I am not going to go into details.

But if somebody wants to later on understand the finer principles behind it, you have to look at the molecular nature.

(Refer Slide Time: 32:05)

There is one more subtle point that I would like to make before I end this particular module and that subtle point relates. Well, it is best to show you by example.

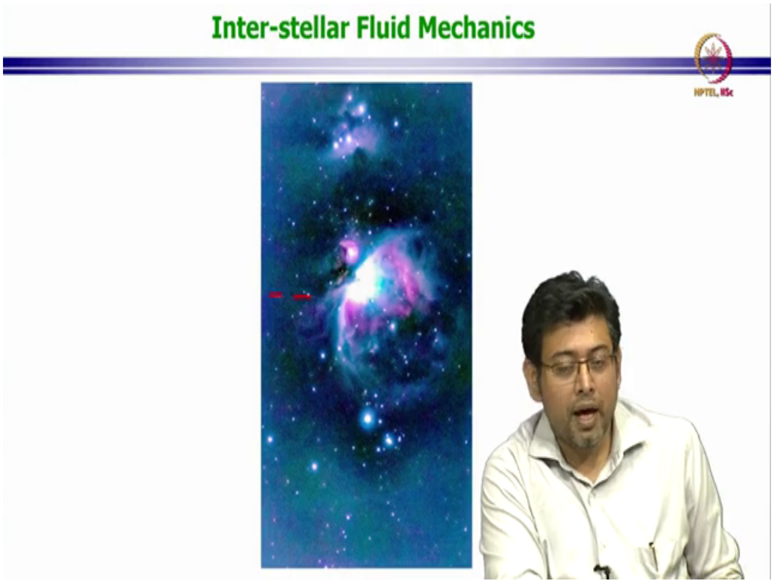
(Refer Slide Time: 32:20)



So, in my spare time I like to do some astrophotography and this is a photo from my house this is this is obviously a tree here on the side. But what is interesting is? These three stars are the orions belt, stars. And it is in this very small box if you have a very clear night and if you see the orions belt just a little bit below it, you, these are the other stars of the orion constellation by the way.

There is a small hazy region, which is, if you are able to look at it? You will be able to see that it is composed of these gases. So, here this is expanded view these are all dots are all the stars this structure here these are gases and this is nothing but the Orion Nebula which is a vast expanse of gases. And gases that are flowing out and flowing out very, very fast. Fast is a relative term and that is the point I would like to make here before we finish off with today's class and this is a picture I took from last year.

(Refer Slide Time: 33:43)



And I took one more this year and I am going to show you that image. There is a lot of noise on this side and I am sorry about that. But you can see the structure overall. There is a satellite trail by the way, this lines these are a satellite was moving across it. Now, these gases, so, these all red colours. These are all gases, the dots are stars you have a strong element of flow here. You can actually, see bow shocks.

I mean it is difficult with my camera but if you have a strong enough telescope, a hubble can see it. For example, you can see both shocks around stars. You, these gases are flowing out at perhaps thousands of kilometres per second. An astrophysicist can tell us better the exact velocity but I took this photo last year, I took this photo this year and they look exactly the same. So, you have this deformation but I cannot see it why is that?

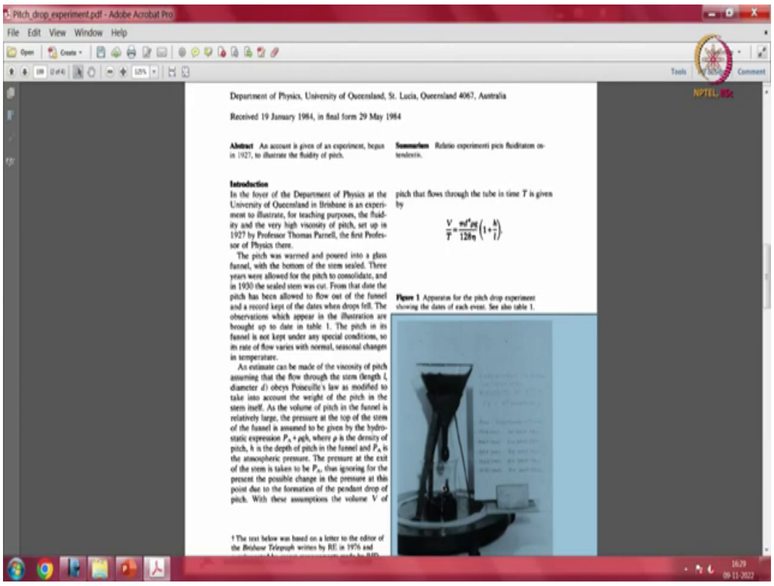
You should think about it the answer here is we have to understand whatever you want to observe. You have to have the experimental resolution to capture that and just because there is deformation does not mean you can see it and the resolution can be in time or it can be in space. I am going to show you an example of resolution in time in a second here. But hopefully this tells you that just because there is deformation that does not mean your experimental technique can capture it here for me.

Even though in reality, the gases are moving out very very fast. To me, this is a static nebula. It is the same that was the last year. It will be the same 10 years on the patterns will barely change and so that is what it is.

(Refer Slide Time: 33:43)

So, I will show you one more example and I want to read out from this very interesting paper. And this paper's title is The Pitch Drop Experiment. You can find this paper online if you look for it and this is written by Edward Dalton Parnell and this paper was written in published in 1984.

(Refer Slide Time: 36:02)

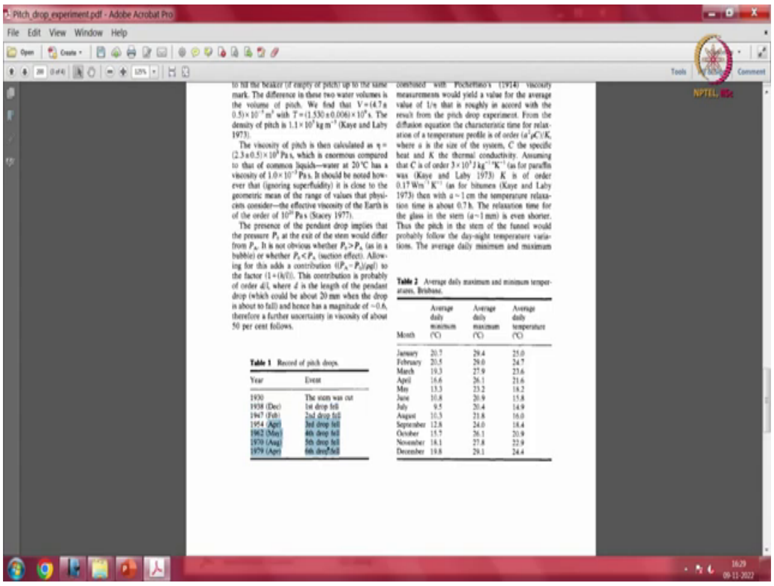


And it describes an experiment that is actually, I believe is still going on in Australia right now. And it describes the experiment right here that in the foyer of the Department of physics at the University of Queensland in Brisbane. In this is an experiment to illustrate for teaching purposes the fluidity and the very high viscosity of pitch set up in 1927 by Professor Thomas Parnell, the first professor of physics there.

So, I am going to not read out the whole thing. What I just quickly tell you what has been happening. So, this is I do not think I can use my; so, if you look at this image on this right hand side, you see a funnel and there is black thing inside it is star. And this star and this funnel here is cut. So, this little drop that has formed right here this this star is actually, going to flow out and actually, going to form in the form of small droplets.

But I think all of you have seen tar. You know that tar behaves almost like a solid body in our regular experience does not it? So, how come it is flowing? Well, if you have to wish really long, I mean, if you want to read the paper.

(Refer Slide Time: 37:14)



mark. The difference in these two water volumes is the volume of pitch. We find that $V = (4.7 \pm 0.5) \times 10^{-5}\ m^3$ with $T = (1.530 \pm 0.006) \times 10^8$ s. The density of pitch is $1.1 \times 10^3\ kg\ m^{-3}$ (Kaye and Laby 1973).

The viscosity of pitch is then calculated as $\eta = (2.3 \pm 0.5) \times 10^8$ Pa s, which is enormous compared to that of common liquids—water at 20°C has a viscosity of 1.0×10^{-3} Pa s. It should be noted however that (ignoring superfluidity) it is close to the geometric mean of the range of values that physicists consider—the effective viscosity of the Earth is of the order of 10^{21} Pa s (Stacey 1977).

The presence of the pendant drop implies that the pressure P_s at the exit of the stem would differ from P_A. It is not obvious whether $P_s > P_A$ (as in a bubble) or whether $P_s < P_A$ (suction effect). Allowing for this adds a contribution $((P_A - P_s)/\rho g l)$ to the factor $(1 + (h/l))$. This contribution is probably of order d/l, where d is the length of the pendant drop (which could be about 20 mm when the drop is about to fall) and hence has a magnitude of ~0.6, therefore a further uncertainty in viscosity of about 50 per cent follows.

combined with Pochettino's (1914) viscosity measurements would yield a value for the average value of $1/\eta$ that is roughly in accord with the result from the pitch drop experiment. From the diffusion equation the characteristic time for relaxation of a temperature profile is of order $(a^2 \rho C)/K$, where a is the size of the system, C the specific heat and K the thermal conductivity. Assuming that C is of order $3 \times 10^3\ J\ kg^{-1}\ K^{-1}$ (as for paraffin wax (Kaye and Laby 1973)) K is of order $0.17\ W m^{-1} K^{-1}$ (as for bitumen (Kaye and Laby 1973)) then with $a \sim 1$ cm the temperature relaxation time is about 0.7 h. The relaxation time for the glass in the stem ($a \sim 1$ mm) is even shorter. Thus the pitch in the stem of the funnel would probably follow the day-night temperature variations. The average daily minimum and maximum

Table 1 Record of pitch drops.

Year	Event
1930	The stem was cut
1938 (Dec)	1st drop fell
1947 (Feb)	2nd drop fell
1954 (Apr)	3rd drop fell
1962 (May)	4th drop fell
1970 (Aug)	5th drop fell
1979 (Apr)	6th drop fell

Table 2 Average daily maximum and minimum temperatures, Brisbane.

Month	Average daily minimum (°C)	Average daily maximum (°C)	Average daily temperature (°C)
January	20.7	29.4	25.0
February	20.5	29.0	24.7
March	19.3	27.9	23.6
April	16.6	26.1	21.6
May	13.3	23.2	18.2
June	10.8	20.9	15.8
July	9.5	20.4	14.9
August	10.3	21.8	16.0
September	12.8	24.0	18.4
October	15.7	26.1	20.9
November	18.1	27.8	22.9
December	19.8	29.1	24.4

It tells you the durations in which a single drop fell, so, it tells you the experiment began in 1930, the stem was first cut. In 1938 that is almost 8 years. The first drop fell, 1947 the second drop fell, in 1954 the third drop and the sixth drop. So, it has been falling in one drop, one drop at a time in about almost a decade one drop takes almost a decade for it to fall. That also tells you that the flow or the deformation that you observe is very strongly dependent upon how you see the phenomena, the time resolution and the spatial resolution.

So, these are two very important things to keep in mind when setting up experiments in order to resolve properly what you want to see. Will not go into details of how to do that? Because these are very experimental dependent or situation dependent things for you to set up. But if you ever do an experiment, you should be very mindful of both these resolutions. And for our course we will straight up assume that you have set it up the right way.

You know the time resolution and the spatial resolution required and then we will only discuss how you interpret? And how you quantify or how you process the data? So, I hope this introduction gave you some flavour of what this course is going to be about. And how we are going to? What type of different phenomena we are going to look at? And I will speak to you more about the mathematical details of the course in the next coming lectures. So, thank you very much.