Principles of Mechanical Measurement
Dr. Dipankar N. Basu
Department of Mechanical Engineering
Indian Institute of Technology Guwahati

Module 01
Lecture 01
Introduction to Measurement

Hello everyone, I am Dipankar N Basu a faculty member of the Department of Mechanical Engineering at IIT Guwahati. Just to briefly introduce myself I did my education from Jadavpur University and then from IIT Kharagpur. Then for little more than 4 years I worked at Bengal Engineering and Science University, Shibpur which is presently known as IIEST Shibpur. And since 2012 onwards I am working at IIT Guwahati as an assistant professor and associate professor. In our lush green and beautiful campus very clean campus also it is nearly 7 years that I have spent and it is an enjoyable journey so far here.

In this department I am associated primarily with the fluid and thermal specialization. And accordingly my primary job is to teach subjects as a thermodynamics, fluid mechanics, heat transfer. I have also taught postgraduate subjects like multiphase flow etcetera. My primary research interest is in the area of nuclear thermal hydraulics, multiphase flow. And high pressure flows both in micro and mini channels. And while most of my research publications etcetera are associated with the computer simulations or numerical analysis of this kind of systems but I have also a very strong fascination towards the experiment.

And it is this fascination towards experiment that has brought me here in this particular MOOC's course on the Principles of Mechanical Measurement. Whenever we are trying to achieve something or trying to understand the any particular phenomenon whatever simplified or what. However, complicated that may be we have to do some kind of experiment first. Because unless we know the nature of the thermal fluidic interaction that is going on inside any system large or small whatever maybe we cannot establish the numerical model for that or we cannot establish any kind of mathematical relationship for that. And hence experiment is the first and foremost thing related to any kind of scientific investigation.

And whenever you are talking about experiments measurements comes into picture. And that is why this topic of mechanical measurement is included in the syllabus of all major undergraduate university curriculum. And definitely in mechanical engineering in certain cases in a few other departments also. However, the focus of our course will mostly be restricted to mechanical engineering only. You will generally find this course included in the 5th or 6th semester of your undergraduate curriculum. And this is some kind of free subjects means it generally does not need any kind of prerequisite apart from of course, the basics of mechanics or some basic principles of physics etcetera.

And that is why it can be taught in any other semesters also, but generally it is included in whatever I have seen from the curriculum of different universities Indian universities at least. That it generally is found in the 5th 6th semester in a few rare cases in the 4th semester. And hence any undergraduate student who has completed all the basics subjects like thermodynamics, solid mechanics etcetera can undergo this kind of course, and no other prerequisite is necessary.

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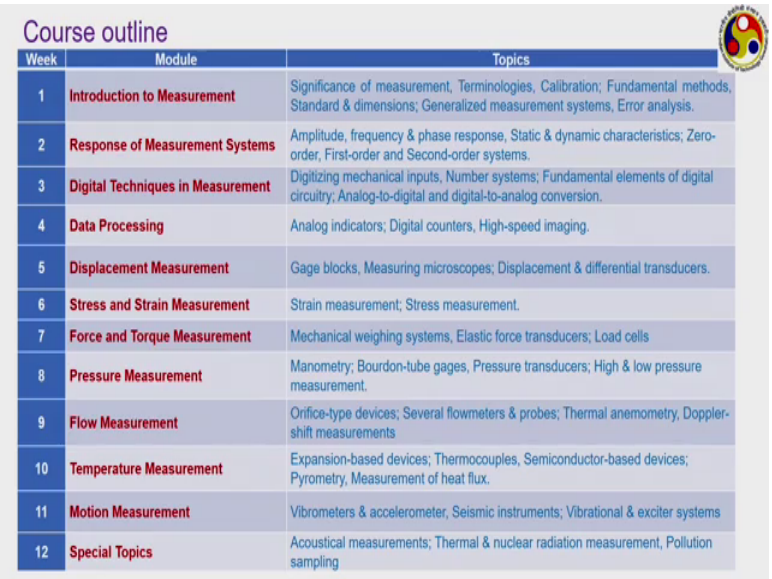

Now, let me see what we are looking to check in this particular course or looking to go through in this course. These are the course structure I am sure you have already taken a look at this one in the webpage of this particular course, but still just to repeat itself. You know it is a 12 week course and accordingly the entire course content has been divided into 12 modules; where in the initial 4 modules we shall be setting different components.

Like in the first week; that is this week itself, we are going to talk about some introductory features of measurement introducing several terminologies also discussing about the different components of a measurement system and also how to understand how to estimate different kind of errors.

Next week we shall be talking about the characteristics and response of different kind of measurement system in terms of static. And dynamic characteristics amplitude frequency and phase response on also different kinds of different orders of system where we shall mostly be focusing on 0 first and second order systems. Because most of the common instruments fall in either of these three categories. 3rd week we know you all know this is the era of digitalizations and we are going for digitalizations in everything and that is why it is important to know the techniques and fundamentals associated with digitalization. So, in the 3rd week we shall be talking about the digital techniques in measurement where some introduction about how to digitize an analog input that will be discussed.

Then different number systems some fundamental circuits that are involved and then analog to digital or digital to analog conversion; so we shall be discussing in detail. Fourth week we shall be talking about data processing different kinds of indicators and counters imaging procedure. And if time permits may be a few very elementary statistical approaches. And then 5th week onwards we shall be entering the real measurement part with all the basics that we are going to learn in the first four weeks 5th week onwards in every week we shall be taking up one important scientific parameter and we shall be discussing about the common techniques of measuring that particular parameter.

Like in week number 5 we shall talking about the measurement of displacement then stress and strain force and torque in week number seven then some very common parameters pressure temperature flow and temperature in the next three weeks. Finally, we shall be discussing about the motion that is velocity and acceleration. And in week number 12 depending on again how many lectures left with us we shall be discussing on a few special topics like acoustics radiation measurement pollution sampling etcetera.

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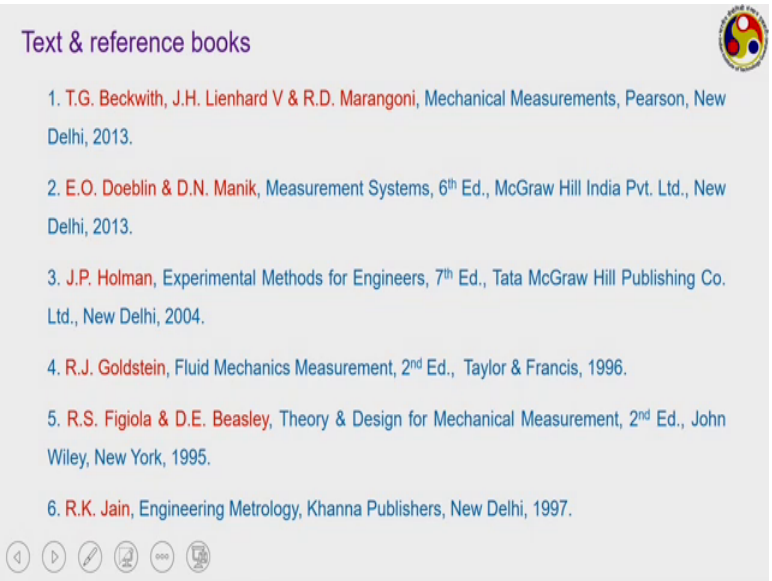

These are some of the books that you can follow there are infinite number of good quality books are available in the market. I have listed a few of them and I shall primarily be taking help from the first three, which is; the book of Beckwith Lienhard and Marangoni, Doeblin and Naik actually it was the book of Doeblin and adopted by Manik in the later years then J.P. Holman a classical books for on experimental methods for engineers.

A very old book of Goldstein Fluid Mechanic Measurement and some help from the others also. And also there are huge quantity of material good quality materials are available on internet so, you can also take help from internet. Now, once we know about what we are going to do here; the first question that I have to answer is what is measurement or what do we mean by that our measurement?

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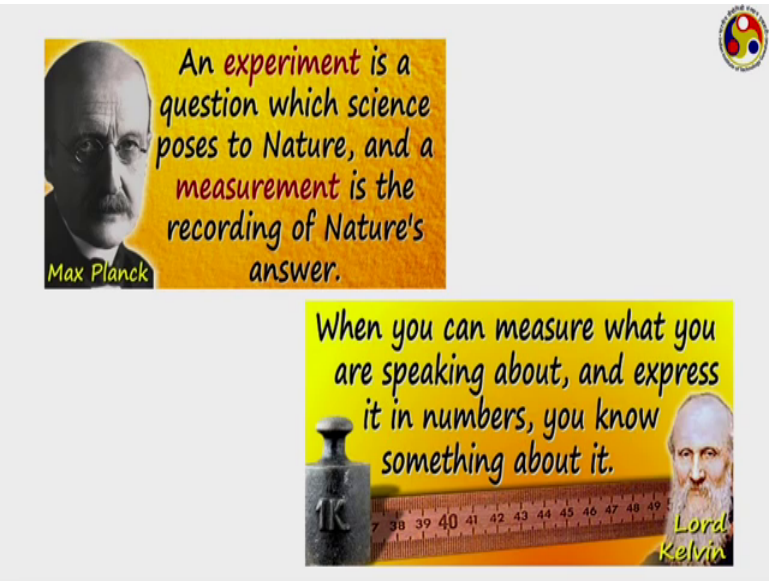

To understand that I would like to quote couple of very favorite quotations of mine; one from Max Planck it is in front of you; ‘an experiment is a question which science poses to nature and a measurement is a recording of nature’s answer.

Because in physics whatever we are doing that is basically interacting with the nature and trying to understand different laws of nature. And in engineering we are trying to apply those laws of nature for certain applications of our interest. And whenever you are trying to interact with the nature we have to understand the response that we are getting from the nature and that is what we are talking about as measurement.

And another one by Lord Kelvin, again a very favourite quote of mine; ‘when you can measure what you are speaking about and express it in numbers you know something about it’. That is basically whenever you are talking about something we have to quantify it somehow. And quantifying it means we have to tell it in terms of some numbers and getting or some converting some natural phenomenon in terms of numbers or natural behaviour in terms of some numbers is what we are going to do in this course of measurement.

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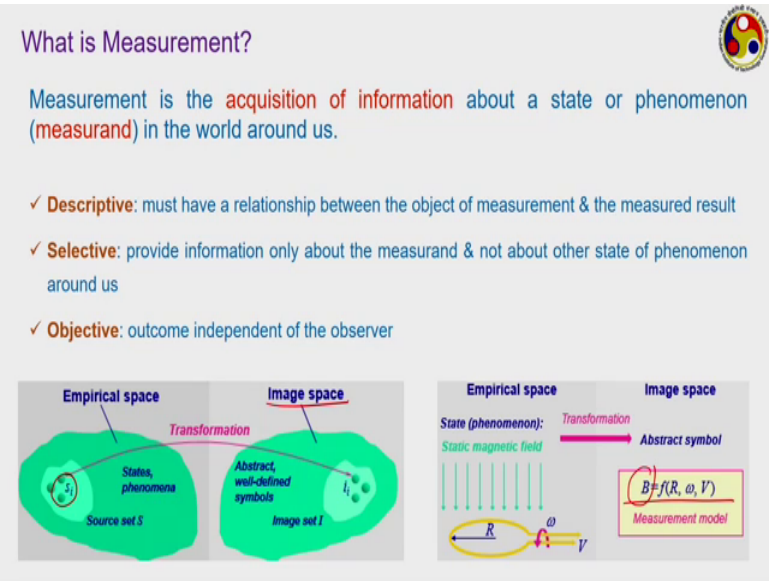

So, accordingly we can put a definition of measurement like; we can say that measurement is the acquisition of information about a state or phenomenon in the world around us. Means whatever going is going around us if we want to get a feel of that then we have to understand or you have to get some information from that and that information collection is the measurement. Now the object or the state of the phenomenon about which we are going to get the information that we are going to call as measurand and this time I shall be using from now onward.

Now collecting any kind of information may not be measurement at all at least from engineering point of view we are mostly interested in numbers. Unless we can express it in terms of numbers we are not going to talk that going to call that as measurement. Like say who you are reading a book when you are going through the book you are also getting lots of informations, but you are not doing any kind of measurement. Because you are just reading you are gaining knowledge, but still you cannot express that in terms of numbers unless in some very special cases; so that is not a measurement.

But whenever what we are seeing a phenomena which can be converted to certain numbers that definitely we can talk we can categorize as an act of measurement. Measurement primarily has to satisfy three conditions; one is descriptive or the first one is descriptive means there has to be some kind of relationship between the object of measurement and the measured result. Before describing this let me give you some

example of all this measurand like your measurand can be anything there is a huge variety of measurand that we can have depending upon what kind of applications we are talking about.

Like in different industrial applications you can encounter the measurement of several very common scientific factors like temperature, pressure, force, stress, strain, etcetera to understand the magnitude of all of them is definitely some kind of measurement. But that does not mean that all these parameters has to be a real one. Sometimes you also talk about some arbitrary parameters which we cannot measure directly, but can measure in an indirect way. Like in thermodynamics we mention about terms like entropy or enthalpy which are only concepts and we cannot measure them practically.

But definitely we can measure them in terms of other directly measurable parameters like pressure and temperature. So, those also will come under the policy of measurement. If we shift our focus to say some manufacturing industry and there people may be interested about knowing the quality of some product that is being developed in the industry. So, explore quality is the measurement in that case. If we talk about finance or commerce there how the market is behaving whether the market is in some ups up. So, it is moving upward or it is going down they have definitely measured in terms of different kind of indices which you have definitely seen those share market based indices etcetera.

And so whenever you are getting those numbers from the share market those are all so the those also can be counted as measurement. And if we move to something else say pharmaceutical industries someone has identified new drug and now want to test that on certain life spaces maybe a guinea pig or a mouse or maybe on human being itself. Then testing itself may not be expressed in terms of numbers, but certain kind of side reactions may be change in the percentage of red blood cells in the blood or my should say the quantity of RBC's or other components in the blood or may be the change in the percentage of certain kind of hormone in the body. If we can express that that definitely is some kind of quantifications and that quantification will lead to a measurement even we move from all this and go to behavioural sciences or in psychology.

They are also people talk about measurement like measuring terms like IQ emotional quotient they are expressed in terms of real numbers. And so those are also coming under the policy of this measurement. So, anything where we are talking about certain kind of

phenomenon and then converting that or quantifying that to a set of numbers we shall be calling that as some kind of measurement. And in this course we are mostly concerned about the mechanical measurands which appear in some kind of mechanical procedure or during some mechanical processes. So, any measurement should satisfy three conditions the first one is descriptive; that means it must have some relation between the object of measurement and the final output that we are going to get.

Like suppose someone is going to measure temperature using a thermometer. The thermometer is a device and you are expecting it to give the temperature of wherever we are taking the thermometer to. But it should not give you in return the IQ of the person who is using is because there is no relation between the two. And it has to be selective means an instrument may have access to several kind of information, but it should pick up the one for which it is being used and give us in the output information about only that one. Say if we talk about an instrument which is used in the weather office for measuring the wind speed.

Now that is generally kept in atmosphere so it is able to sense whatever is there around it temperature, pressure etcetera also, but if the objective of the instrument is solely to return the wind speed then it should sense only the wind speed remove all the other kind of things coming in all the other kind of inputs coming in and provide us at the output only information about that wind speed. All the other informations coming in the picture those generally call in terms as noise. These informations about pressure temperature in this particular example which are coming in we can call them as noise because those are not our objective. Our objective is to get the idea only about the wind speed with that instrument.

Now both of this both of these aspects of measurement descript being descriptive and being selective both are essential, but none of them are necessary or sufficient condition. But the third one is where it says that the measurement has to be objective; that means, the whatever output it is going to give that should be independent of the observer. Means if we are taking the measurement of a body temperature using a thermometer then it does not depend who is using the thermometer, whether it is a doctor or whether is a common person it should return you the same value and this is a sufficient condition.

So, descriptive and selective those two has to be satisfied, but objective is also is another very important aspect which has to be satisfied or a measuring instrument should satisfy the third one truly speaking a measuring instrument should satisfy all three. Let us take one example let us say here we have a system from about which we are trying to get some kind of information. So, this is the system that we are talking about and S is some kind of parameter which are trying to measure. So, by the process of measurement that is using whatever measuring tool that we are going to use we are going to convert this measuring or convert this natural phenomenon or this state to an image space.

And we are going to represent this in terms of an well defined symbol or maybe a combination of several well defined symbols. Why you are calling this as image that is because whatever names we are using that nature provided us, but rather we have used these names like say if we are interested about knowing the temperature of this particular location then we have decided to call that as temperature. And also whatever value that we are going to use whatever scale for temperature that we are going to use that is our own decision only. And that is why we are calling this as image space like let us check this out it is a very standard phenomenon a conductor is being subjected a static magnetic field.

And according you are getting some kind of phenomenon happening then using our understanding and also our convenience we can always convert this one to an equation like this where the magnetic field intensity can be represented as a function of these three quantities maybe the radius of the coil the kinetic sorry. The rotational velocity and also the voltage this, but it is our choice to identify these four parameters that we are talking about. That means, it is not that the nature has told us about this magnetic flux intensity or any other parameter we have decided this.

And also from our experience with this phenomenon we have understood that these are the three parameters which can be most influential in deciding the value of this B. And therefore, during the measurement process we try to monitor these three parameters to get an idea about this B. So, accordingly any measurement process always involve some kind of experience that is which parameters to focus on which parameters to keep the emphasis. And accordingly we get certain kind of output when we shall be discussing in more detail about this particular transformation.

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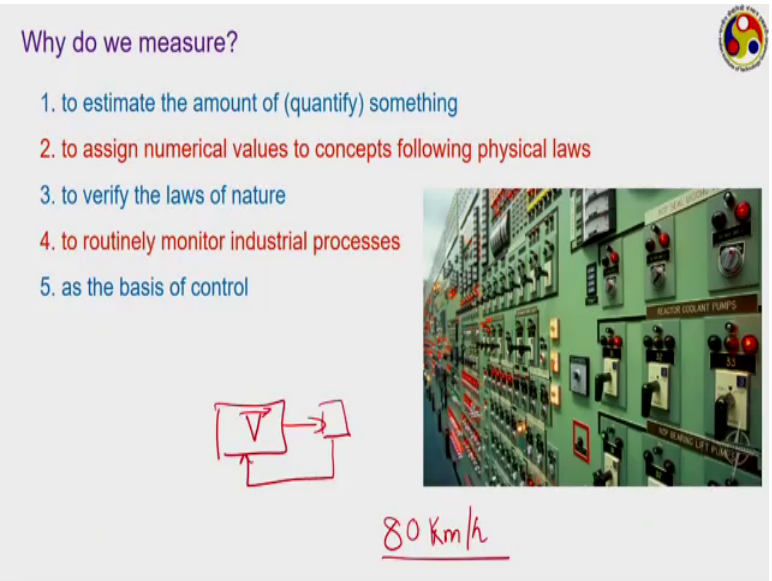

But before that why do we measure? The question that came earlier to estimate the amount or quantify something. That is it we should get some number or some numerals as the output some consist based upon certain kind of physical laws or may not be physical laws even certain abstract things also we can quantify in terms of numbers. And when you are getting those numerals as the output we are calling that as a measurement that can be some very physical thing like length or mass of something or some very obstructing like IQ of a person but we should have some kind of numerical representation. To verify the laws of nature I shall be coming back to this way in the next slide.

Next to routinely monitor industrial processes certain industrial processes require huge amount of measurement simultaneous measurement of significant parameters to get a feel about what is going on. Just to give you an idea I have a put a picture of a control panel of a power station. Just see how many switches or lights are there; because to ensure that the plant is operating properly and also to understand it is what output it is producing the operator or the control panel personnel may have to monitor hundreds and hundreds of parameters simultaneously. Sometimes which may will be beyond human control and your human capability and we have to go for computers.

But simultaneously they have to keep an eye on all these parameters you probably have seen pictures of the cockpit of an aircraft. There are humongous amount of switches or

controls or dials etcetera are available. Because people have to or rather I should say the pilot the operator has to continuously monitor all these to ensure that the flight is healthy. Even in our car dashboard you may have seen there are quite a few several dials giving us an idea about the speed at which it moving, the temperature of the engine, the amount of fuel that is left there and also several other switches; means how to operate the headlights how to operate the wipers and several others.

So, all this continuous monitoring or routine monitoring may will be necessary in several industrial processes. And even maybe in our day to day process also like say you want to make a cup of tea or maybe you want to make four cups of tea. Then definitely well be taking some quantity of water and put that into a container and then put that on some oven for heating. Now firstly, thing you need to know how much amount of water you should put. So, you should first measure the volume of water that you are putting in that container. Then once the water gets heated up we are going to add the tea leaves to that.

Now how much heated up means what we are talking about it need to a certain kind of temperatures then only we should add the tea leaves so, and also how much quantity of tea leaves we have to put in. Again once we have added the tea leaves then if you want to add sugar or if you want to add milk then you need to know their quantities as well. And once you have added all these ingredients then how much time you will allow that mixture to boil. So, there are several measurements involved in those that such a simple situation also. You may think that we do not measure this mass of chilies or volume of water at a time because you may be experienced with that.

You already know that maybe it is a with a particular spoon you may add one teaspoon or rather with a particular spoon you can add one spoon of tea leaves to get that amount of tea. But if I change the tea spoon and you have access to only spoons of different sizes you may be in some trouble. So, we have to continuously measure certain things in our daily lives also to get every process or every operation done smoothly. And the next step to operation is control measurement is the basis of control. We need to know the value of any particular parameter to control it like suppose in your in a simple flow channel let us say this a channel through which some fluid is flowing.

Now, you want to control the amount of fluid that is flowing through this channel. And for that purpose you are adding a valve to this. Sorry, I am quite poor in using this

particular pen, but let me try to do. Now you want to control the flow of the fluid using this valve, but to control the flow you need to know how much is flowing through this. Unless you have any idea about how much what is the flow rate of fluid through this channel there is no point operating the valve or a more complicated one. Suppose you are driving a vehicle and you want to ensure that the speed of the vehicle never cross say 80 kilometre per hour.

And then to control the speed to this particular limit you should first measure this particular value or I should not say this value whatever is a velocity which if this car is moving it should measure this or maybe the speed at least. And depending on the output of this velocity measuring instrument let us say I have a velocity measuring instrument here which is giving you the idea about the velocity of this it is going to give a feedback to the engine of the car. As long as the velocity is less than 80 kilometer per hour there is no issue.

But as soon as the velocity crosses this 80 kilometer per hour it may send some signal to the engine to produce the or I should say to reduce the work output that engine is giving. So, that the velocity comes down or it may send some signals to the brakes. So, that it can be applied on the wheels to reduce the velocity to some safer limit maybe below this 80 kilometre per hour. So, this kind of control situation will always start with certain kind of measurement.

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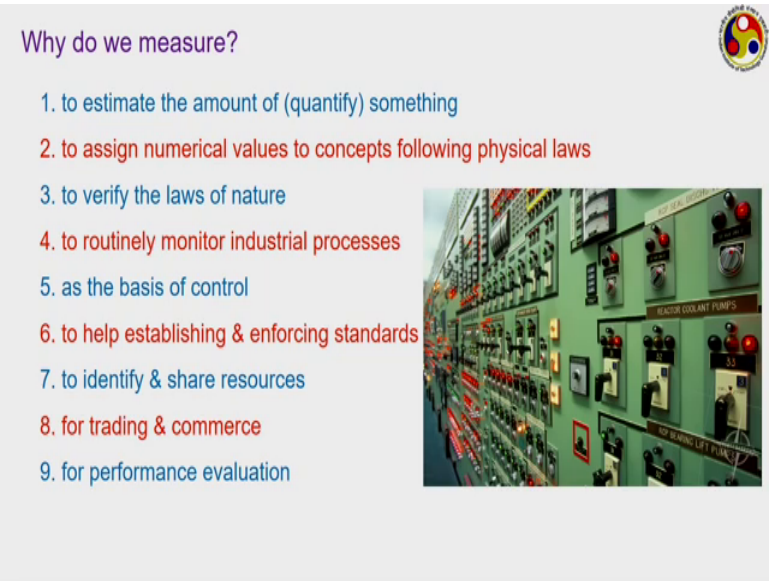

Next to help establishing and enforcing standards I shall be coming back to the standards also again. And to identify and share resources to know how much energy reserve is available in a particular country. For an example like you all know the fossil fuel reserves are coming down drastically. But still how much is left how many more years we can survive with that. So, we need to know such kind of information here we are talking about natural resources we may talk about any other resources also like say in our houses.

So, a day to day we have to keep a track of how much foodstuffs or how many vegetables etcetera they are in store they are in the refrigerator. Because whether it will sustain for the next day or not if it will not sustain then we have to go to the market and purchase some new and then refill the refrigerator. So, that is what we are talking about identifying resources maintaining that sometimes sharing those informations also. For trading and commerce I have already given the example of share market or in corresponding dealings.

So, to understand the trade proper trade properties to understand the direction at which it market is going we need to measure the characteristics properly. For performance evaluation like you guys are doing this course and many of you may be appearing for the exams. Now how to evaluate a performance in terms of marks in terms of grades?

So, we have to quantify whatever you are writing in the final exam copy somehow we have to quantify that to get the grades. So, that evaluation is also a kind of measurement and there are several other kind of applications or other kind of usefulness of measurement also we can identify the same way.

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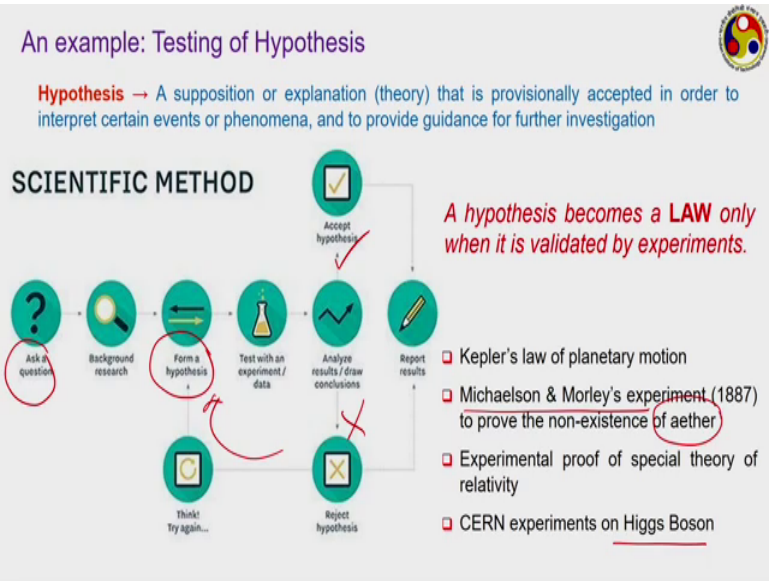

These an example there was one point if I go back to verify the laws of nature. So, coming here the testing of hypothesis is basically the same thing that we are talking about. A hypothesis refers to certain kind of theoretical explanation about something that is a provisionally we are going to accept the hypothesis about certain kind of event or certain kind of phenomenon. You can think about that hypothesis is some pre planned kind of conclusion that this phenomenon will lead to this kind of physics or it will involve this kind of physics.

And once you have set up the hypothesis then we are going to do the experiment do certain kind of measurement to test whether our hypothesis is correct or wrong. Any kind of scientific investigation generally starts with setting of hypothesis and then follows the process of experimentation or measurement to check whether your hypothesis is valid or invalid. Like one example here; first our question is to or first our target is to ask a question that is basically to face a situation something we have to know about a certain event or certain phenomenon.

We do some kind of background research and from there we form a hypothesis that is this phenomenon is happening because of this particular thing. And once we have formed this hypothesis then we shall be testing that with experiment we shall be analyzing the experimental data if the data supports our prior concieved hypothesis then hypothesis

will be accepted. But if does not support the hypothesis will be rejected and we have to go back to check it.

A hypothesis becomes a law only when it is validated by experiment that is to set up any laws of nature we have to first consider hypothesis and then we can validate this only through proper measurement. Here are a few examples first is Kepler's law planetary motion. Now this laws were proposed 100s of years before this apple omission and others and when Kepler first proposed his law that all the planets there are three laws one of them is all the planets orbit around the sun in elliptical paths. Now, he was not able to go outside the universe or I should to go outside the planet outside our planet to see visibly to personally see that do some kind of calculations he did and accordingly came with this one.

And only later on it was through experiments and through the several modern analysis it was proved to be correct. A much better example can be this one you may have heard about the existence of a third earlier it used to be believed that Aether is some kind of invisible substance which exists everywhere and for the movement of all electromagnetic waves for electromagnetic forces or gravitational forces to act we need the need this Aether. Now, it was the. So, that was some kind of hypothesis and it was only the experiments of Mickelson model is in 1887 it was the existence of Aether was discarded.

And they were the first experimentalist who to prove the non existence of Aether later several other things were also done. The experimental proof of special theory of relativity very recent experiment the sound experiments for as the proof of Higgs Boson. Higgs Boson was proposed in 1950's, but that was only at hypothesis only certain kind of postulate because that was based upon certain kind of theoretical observations or theoretical analysis. But only following this set of experiments the existence of boson was identified and now it is an established scientific fact.

So, we need to go for experimentation were measurement is probably the most important concept to establish this kind of laws of nature. Like the laws of thermodynamics they are all phenomenal logical laws means they were not proposed based on any kind of mathematics rather they are proposed only from experiments only from our observations. So, the testing of hypothesis is a very important area or to set up the laws of nature and a very important application of the laws of measurements or principles of measurements.

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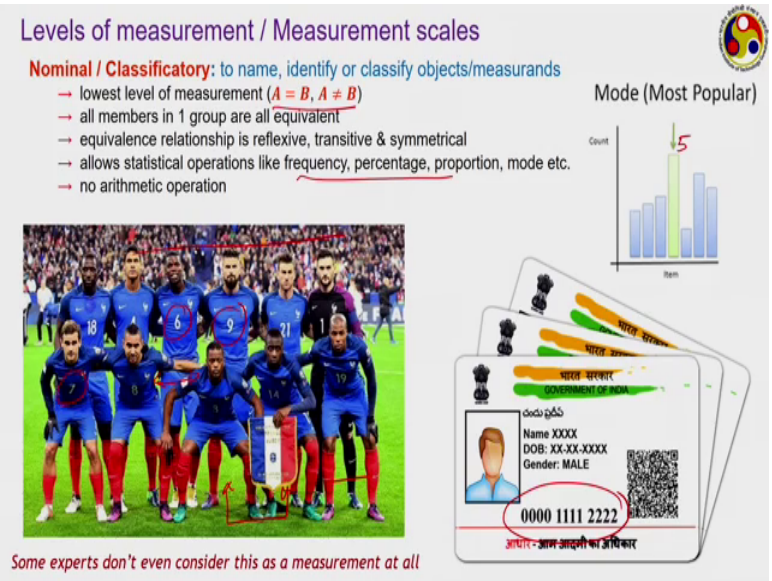

Now, there can be several levels of measurement primarily we classify different measurement scales or levels of measurements into four categories and the first one is a nominal or classificatory. It is a very very basic kind of measurement the simplest one or the lowest level of measurement, which we just check this particular thing whether A equal to B or not. So, it is generally used only to name identifier classify different objects or measurements without properly quantifying them I should say.

All members in a single group are considered to be equivalent like one example here you can see this is a football team everyone is having a jersey number there. But the numbers that is given on their jerseys like this 6 and 7 they do not tell anything about this persons it is not saying that the person wearing jersey number 6 is a better player than the one wearing 7 or the one wearing seven is a better person better player than 6 these are just indicators rather from nominal measurement point of view all of them are players.

So, all of them belong to the same group that is all the player of France football team. So, this nominal measurement or nominal level of measurement they will not be able to classify between these two persons it will treat them as same this kind of equivalence relationship is ship is reflexive transitive. And also symmetrical another thing is that like say let me pick up jersey number 9. Here we have one person wearing this jersey number 9 and from the opponent team also there may be another player who is wearing the jersey number 9.

Now they belong different groups, but that is not because they are wearing the same jersey number or I should say there is no effect of the jersey number bit for them to be classified in different groups that is only because these set of players belong to the team of France and they belong to the other group. So, it is a plain classification yes or no kind of thing or whether here whether these two players belong to the same group yes then they will be put in the same group whether this player and someone from the opponent team belong to the same group or not the answer will be no.

So, this is more an yes or no kind of answer this classification is going to give. It is going to allow only very few limited statistical operations like frequency percentage proportion or maybe the mode. No arithmetic operation like addition subtraction multiplication etcetera are allowed. Another very good example can be the Aadhaar Card that we are using in India or any such social security cards or social security numbers. Now the card definitely contains lots of information about you.

But this number which has been assigned to you that is that may be a bit random basically this number is not going to talk anything about you as a person with such a level of measurement we can do as I have already mentioned very limited operations mode may be one of them. I hope you know mode refers to the largest number. Like say there are a group of students and each of them have certain number of candies.

Now some person may be having two candies another one may be having three candies one may be having five candies. So, the mode will only give you the maximum one that is all. But this level of classification is not going to put any kind of differentiation between the students. And that is why several experts do not even consider this as a measurement at all they consider this just as a classification. But most of the books on measurement put this one as the first level of measurement that is why I am also mentioning it here.

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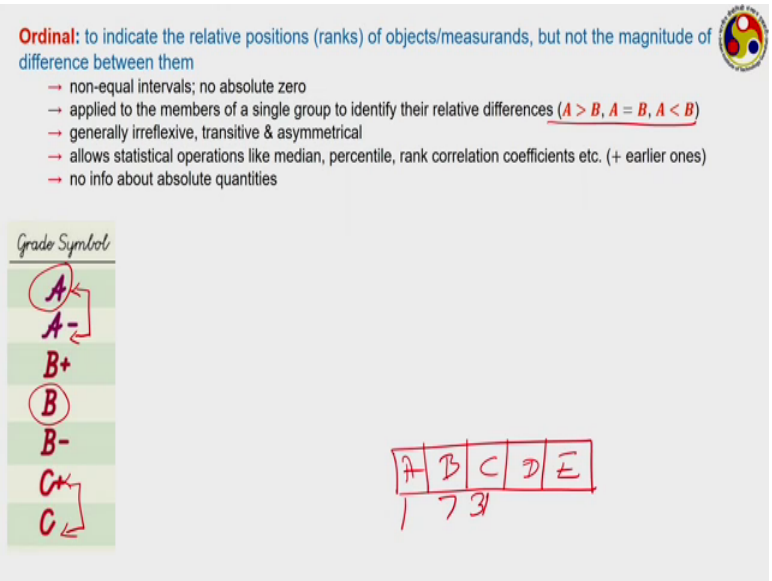

Now, the second level is ordinal assign certain kind of number, but that is more as a rank. And not to reflect the exact performance that is it is going to indicate the relative position of the objector or measurand within a group, but it will not give you any idea about the magnitude of difference between them. Let me give the example of the grade system. So, you know that the students who have got this A grade definitely has done much better then the student has got B grade.

But that does not give you any idea about the difference in marks between A and B it also is not going to give you any idea about the exact mass that has been obtained by all the students who belong to this A group. And say A and A minus I should say are two neighbouring groups and similarly C plus and C are two neighbouring groups. It is also not going to tell you any idea not going to give you any idea that is whether the difference in marks between the students belonging to group A and A minus whatever is the difference whether that is same for this case of C and C plus that maybe same may not be same it does not matter.

Actually in this kind of classification it gives simply a rank kind of thing it will only check whether a is greater than B A equal to B or A less than B. So, it is and all these divisions are non equal divisions means it is not that what if say I have total 50 samples I am dividing this 50 into 5 groups. And then I am giving them name as A B C D and E it is not that each of the groups are going to have 10 samples under this or certain equal

intervals. It may happen that in group a I have one group B I have 7 and group C I have 31 a very very random distribution it just talks about A B and C following some kind of order in terms of certain quality A is better than greater than B and B is greater than C or vice versa.

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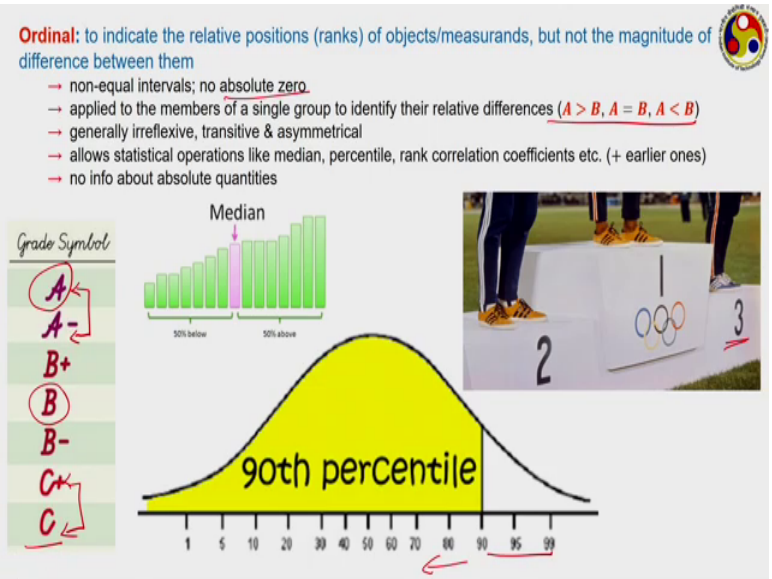

Another example of a podium; this podium is going to show you only that the person standing at 1 has done better than person standing at 2. And the person standing at 2 is going to show you or is going to indicate that he has done better than person standing at 3. But no other information about the exact difference between them if this we are talking about certain kind of athletic event say all of them has participated in 100 meter run then the time with which one has finished how much higher is that compared to the person 2 or 3 this kind of classification or this kind level of measurement is not going to give you that idea.

But they will classify the performance according to certain kind of rank there is as there is no interval you are talking about is purely relative one. So, there is no need of absolute 0 like in the grading system if C is the lowest grade that does not mean that the students who have got C C grade has got a 0 marks. Because that is only relative they may have got 30 percent or 40 percent marks ah. But there is no need of absolute 0 because our classification or I should say this ranking is purely a qualitative one and comparative one.

So, some more statistical operations are allowed earlier ones definitely are allowed and if you more like median is one median just speaks of the middle of a set 50 percent is below these 50 percent. Above this another very important and very common one you must be knowing is percentile. Someone has obtained 9th percentile means 90 percent of the student has got less than him, but that does not tell him that he has got 90 percent of marks. It only tells that 10 percent of student performed more better than him and 90 percent inferior to him that is all it is purely a relative positioning and no idea about the absolute quantity.

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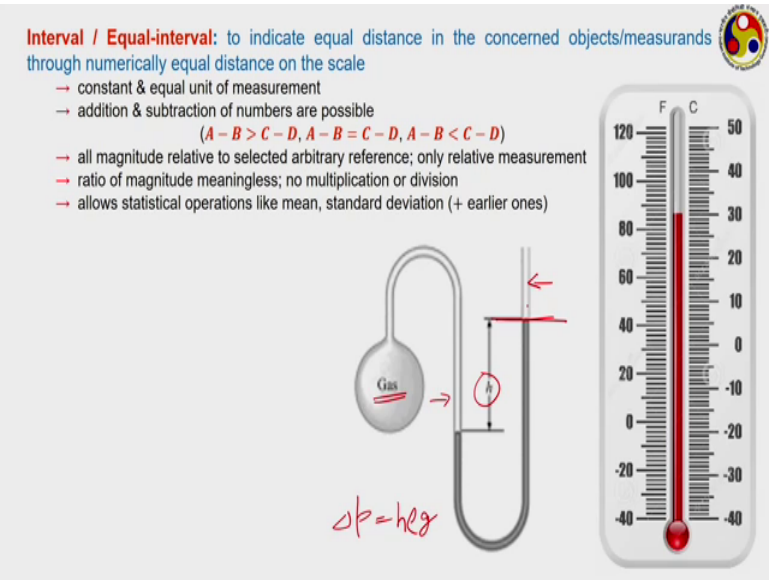

Next is interval or sometimes also called equal interval scaling recall interval model. Here we have equal interval in the concerned objects or measures through some numerically equal distance on the scale. Here we use on some constant and equality of measurement and operations like addition and subtractions of numbers are allowed. Very good example can be the temperature scale here we have a thermometer which is showing the temperature scale both in Celsius and Fahrenheit I am sure all of you have idea about this that is why I am picking up this example.

Now you can we can clearly see from this scale that how the purse someone who has sorry a temperature value of 10 and a temperature value of 30 or I should say we have started with say temperature of 10 and during some experiment we have moved up to a temperature of 30. So, the change is twenty that is exact or I should say this equal unit of

measurement or equal distance I am talking about whatever is the distance between minus 10 and 0 the same is the distance between 10 and 20 that is equal. So, there has been divided following certain kind of principle and we are following that over the entire scale of in the measurement.

Like a change in temperature from 0 to 50 will concerned a change of 50 degree similarly a change in temperature from 500 to 550 will also constantly change of change of 50 degree same in the Fahrenheit scale. But one problem is that here this measurement is also somewhat relative because we are doing everything based upon an arbitrary reference point. Like something which is having a temperature of 10 say we have an object which is having a temperature of 10 degree Celsius and another object having a temperature of 20 degree Celsius; that does not mean that temperature of B is double of temperature of A.

Because here we do not have any absolute 0 temperature this 0 which is shown on the scale or say 0 in Celsius scale this is just a choice like the temperature at which water gets converted to ice under normal atmospheric condition we are calling that as 0 degree Celsius that is a purely relative positioning. And so we can do addition or subtraction kind of operation, but we cannot compare any kind of ratio based calculation multiplication or division. But still this kind of situations allows us several other kind of operation to be done like mean or standard deviation.

Here I have another example a common manometer this one also probably you have heard or you have learned about in your fluid mechanics course. So, here this particular arm is open to the atmosphere and this arm is connected to the container whose pressure needs to be measured. Now we know that the fluid is fluid columns in both arms are showing a height of height difference of h. And so and the difference in pressure between the two is equal to h rho into g where rho refers to a density of this manometric fluid g is the acceleration due to gravity.

So, you know the pressure difference between the two columns. But to know the exact pressure in this gas column we need to know the pressure at this particular point which primarily is the atmospheric pressure. So, whatever measurement we are doing that is based upon atmospheric pressure only and if we do not want to consider the atmospheric

pressure in our calculation we are only going to get the gorge pressure which is a relative measurement.

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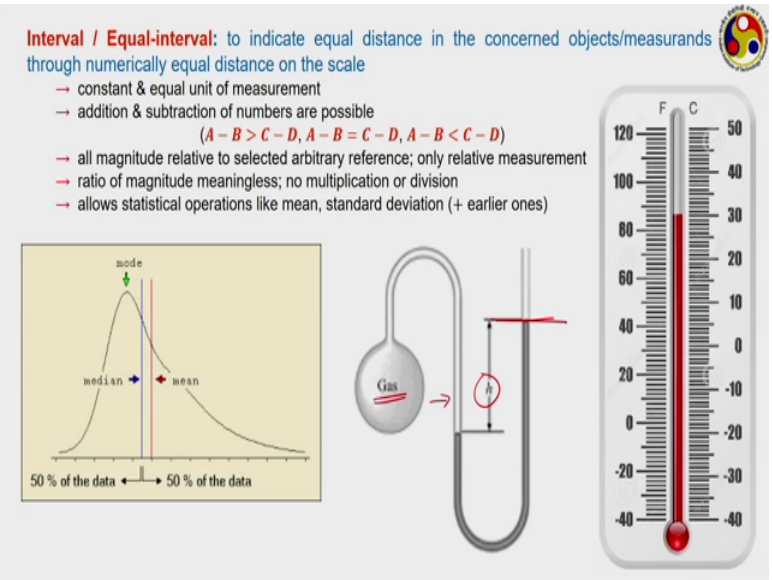

The statistical operations like mean standard deviation etcetera can be done more or less all kind of statistical operation apart from very restricted one or two which requires this ratio to be calculated that can be performed on this interval scale.

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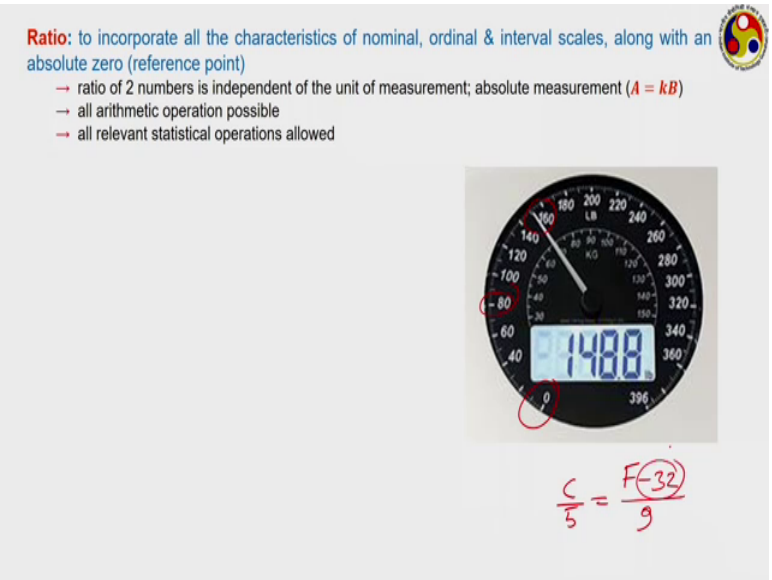

And the final one is the ratio scale in case of ratio scale we have an absolute 0 present. So, all the characteristics of the earlier three that is nominal ordinal and interval are

present plus we have a fixed reference point, like you we take up this example of a weight measuring dial truly speaking a mass measuring real. Here we have a proper 0 and this 0 is different from the 0 which was there in the thermometer this is this refers to 0 mass that 0 on thermometer 0 degree Celsius or 0 degree Fahrenheit are different locations.

And that is why they does not give us any information or I should say that does not tell that when the temperature reading which is 0 degree Celsius there is no temperature there But when the mass reading which is 0 here that definitely indicates the mass is 0 so there is an absolute 0. And hence suppose a reading of 80 on this scale and 160 on this scale we can definitely compare them like a person weighing 80 pounds and the person weighing 160 pound we can definitely say that the 2nd person is weighing double compared to the 1st person.

And we can also relate this case using some kind of multiplication factor like in case of previous scale Celsius and Fahrenheit scale was there in example. We know that we cannot write that C is equal to k into F. This is wrong rather we know that corresponding relation is something like this C by 5 is equal to F minus 32 by 9 that is because in one scale we are choosing 0. But in the other scale at 0 degree Celsius corresponds to 32 degree Fahrenheit. So, it is not a straight forward linear relationship.

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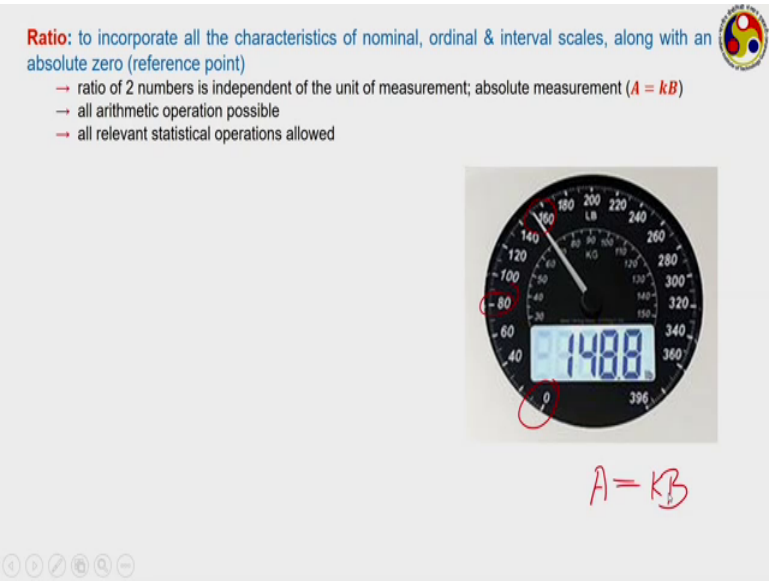

But in this scale say if A refers to the mass in kg and B refers to the mass in pound. We can clearly say that A is equal to k into B this kind of ratio is permitted in ratio based measurement.

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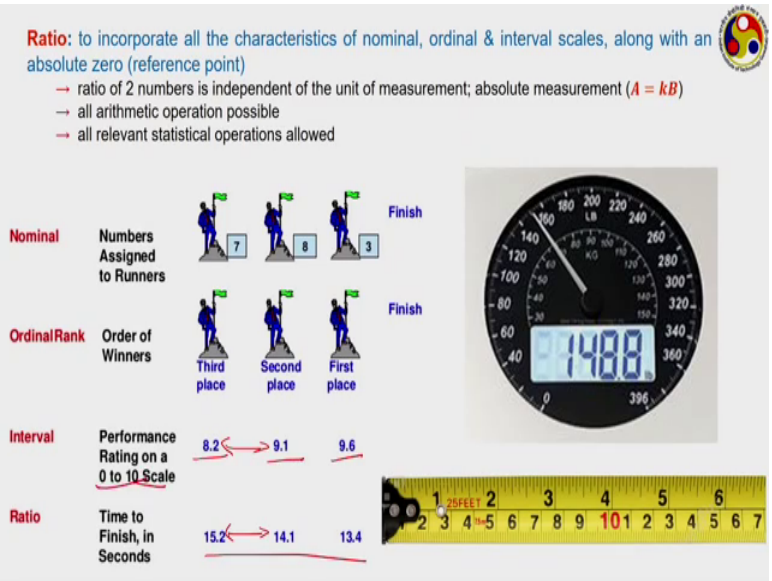

So, here we can do any kind of arithmetic operation and all kinds of statistical operation also can be performed on this. This is another very common example of a measuring tape here again two scales are shown the inch or feet on one side millimetre and centimetre. On the other side we can use either of them to measure the same thing and also we can use the relationship between an inch and centimetre to get their mutual conversion. Like clearly we can see that a measurement of 2 feet corresponds to something like 5.1; 5.1 centimetre.

So, whatever may be the conversion factor like we know one inch correspond to 2.54 centimetres using that kind of conversion factor we can always interchange from one scale to another scale. So, a figure to compare all the four kind of scales that we are talking about. Primarily we have to consider or any scale of measurement need to have I should not say any scale of measurement rather scale of reference scale of measurement generally constants three factors. Factor number 1 is the comparison or rank, number 2 equal interval, number three absolute 0.

The first one does not of any of them, second one the ordinal adds the rank factor into this third one the interval or equal interval that adds that equal interval characteristics

and finally, the fourth on the ratio add that absolute 0 as well. So, if you think about a an example where several runners have participated in say 100 meter or 200 meter run say 100 meter run because the values are quite arbitrary for 200 meter. So, here the nominal scale will assign some kind of jersey number kind of things to them say there are three persons they are jersey numbers of 7 8.

And three all belong to the same group and no other information about them ordinal scale is going to tell that who has finished as first who has second west third and the same way rank all the participant. If there are 10 participants well nominal scale is going to give you only their jersey numbers ordinal scale is going to give you their rank from 1 to 10. Interval scale can judge their performance based upon a certain standard like if we pick up a scale of 0 to 10.

Then it can give certain value it can assign certain value which will allow us to compare their performance somehow like if the first person is given a scale 9.6 and second one 9.1. Then we can clearly see as per this particular scale there is a 0.5 difference between them. And then there is a difference of 0.9 between second and third. So, from there at least this conclusion we can draw that whatever was their difference in timing between first and second their difference in timing between second and third may be larger.

And that is what ratio scale tells us that gives us the complete picture that gives you the exact value of the time that they have taken like in case of the first one weighs well the first person is finished in 13.4 second one has taken 14.1; that means, there is a difference of 0.7 seconds. But there is a difference of 1.0 once again between second and third and which is also reflected by this difference in this. But still this interval is some kind of relative depending upon the choice of your scale whereas, the ratio is giving you the exact number.

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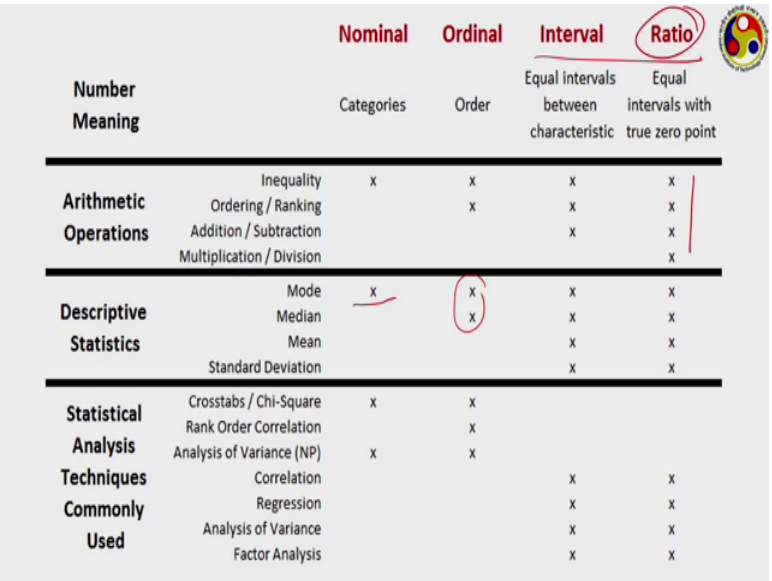

		Nominal	Ordinal	Interval	Ratio
Number Meaning		Categories	Order	Equal intervals between characteristic	Equal intervals with true zero point
Arithmetic Operations	Inequality	x	x	x	x
	Ordering / Ranking		x	x	x
	Addition / Subtraction			x	x
	Multiplication / Division				x
Descriptive Statistics	Mode	x	x	x	x
	Median		x	x	x
	Mean			x	x
	Standard Deviation			x	x
Statistical Analysis Techniques Commonly Used	Crosstabs / Chi-Square	x	x		
	Rank Order Correlation		x		
	Analysis of Variance (NP)	x	x		
	Correlation			x	x
	Regression			x	x
	Analysis of Variance			x	x
	Factor Analysis			x	x

Another way of comparing them if we talk about the number meaning the number that these corresponding measurements are assigning. The nominal is only going to talk about categories where ordinal is going to give you order or rank interval is going to give us some equal interval about characteristics following some uniform scale and ratio is going to give you equal interval, but a proper scale with an absolute 0 or a fixed point of reference.

The arithmetic one important or good examples between these two can be like we have talking about the example of thermometer. So, when you are talking about Celsius and Fahrenheit temperature Fahrenheit temperature scales our choice of reference is quite arbitrary. However, if we talk about an absolute temperature scale the Kelvin scale there we have an absolute 0 point which is a fixed point of reference. And so if we measure temperature with respect to absolute Kelvin scale then that will come under this ratio scale.

If we talk about arithmetic measurement no or arithmetic operations nominal is only going to allow us equality or inequality kind of operation. Whereas, we can be the ordering in ordinal addition subtraction kind of our arithmetic operation is permitted on interval scale. And all including multiplication and division any kind of ratio based operation are permitted in this ratio. Now we can do only the mode calculation in the

first one median and mode both can be calculated here we can also calculate median mode mean standard deviation etcetera.

In the remaining two some very common statistical analysis are listed here like nominal and ordinal allows very simplistic calculation like chai square or maybe analysis of variance. But more modern more advanced tools like correlation regression can be applied only on interval or ratio scales. Some idea about some of these methods we shall be getting in our later chapter. So, in this course we shall mostly be talking about the interval and ratio because mechanical measurement primarily uses either of these two.

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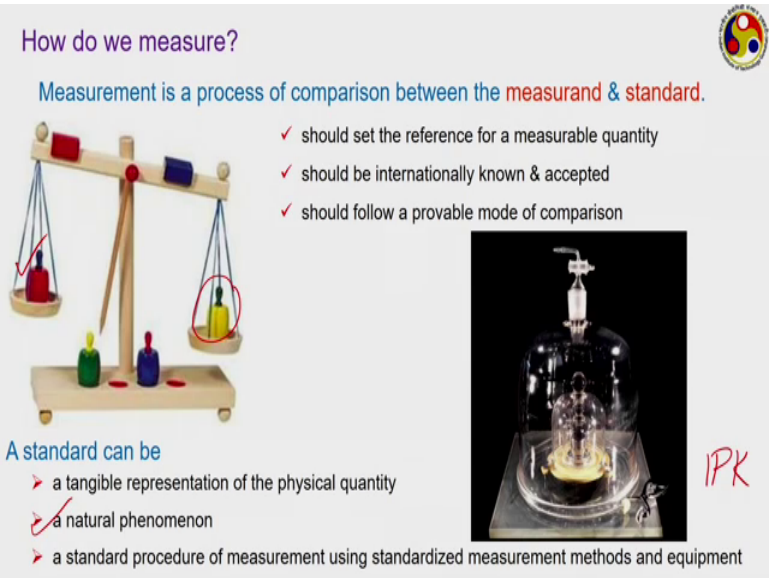

Now, next question is how do we measure. So, we know what is measurement, we know why we have to measure and you also have got some idea about different levels of measurement. Now we need to know how to be perform the measurement. Now the process of measurement is a kind of comparison between the measurand and standard like this. Here, if this is your standard we are going to compare the value of the measurand or value of the concerned object with the concern value of the standard. And by the process of comparison we can get the value for this measurand a standard should set the reference for a measurable quantity should be internationally known and accepted.

And also should follow a provable mode of comparison during the measurement process. Now, what can act as a standard we can take several things like a tangible representation

of a physical quantity a natural phenomenon which has to be repeatable and reliable and then that can act as a very good standard. A standard procedure of measurement using standardized measurement methods and equipment can also sometimes be selected. But nowadays we mostly prefer to go by this example I hope you know what this is. This is the standard mass of cylinder or rather this is a cylinder which corresponds to a standard mass of 1 kg.

You all know that 1 kg is designated as a mass of 1000 cc of water at 4 degree Celsius. But to set up the standard as for the international agreement in 1818's a new material a new alloy was formed which contains 90 percent platinum and 10 percent iridium which is generally called IPK International Prototype Kg or International Prototype Kilogram. And using that IPK which is generally a very hard material with a very high corrosion resistance and high density also. This particular cylinder was formed this cylinder is having a diameter of 3.9 centimetre and also height is also same as the diameter and height are equal to each other.

So, it has the least possible cross section area as I should say least possible surface area which raises the corrosion. And then this is maintained in a vault 8 meter below the office of internal standards of weight and measures at Paris. There you can see there are three which are put on this is just to protect this one there are 6 official copies of this one available this is only one of them which is kept at this Paris. And 6 official copies in different other standard laboratories of the world and but it has been found that the mass of this one has changed little bit like there is a change of about 50 microgram over this period of 120 years.

So, there is a discussion going on about to replace this one as a standard for mass most of the other standards like length or time whatever was selected earlier that has been replaced by natural phenomena nowadays. And this one also may get replaced by a natural phenomena like two of them are very much in consideration. One is to use the Avogadro number and use the molecular mass as a kind of standard other is certain kind of gravitational force and electromagnetic force parity using the Planck constant. So, that may come in future, but this is a very good example of what you are talking about under standard.

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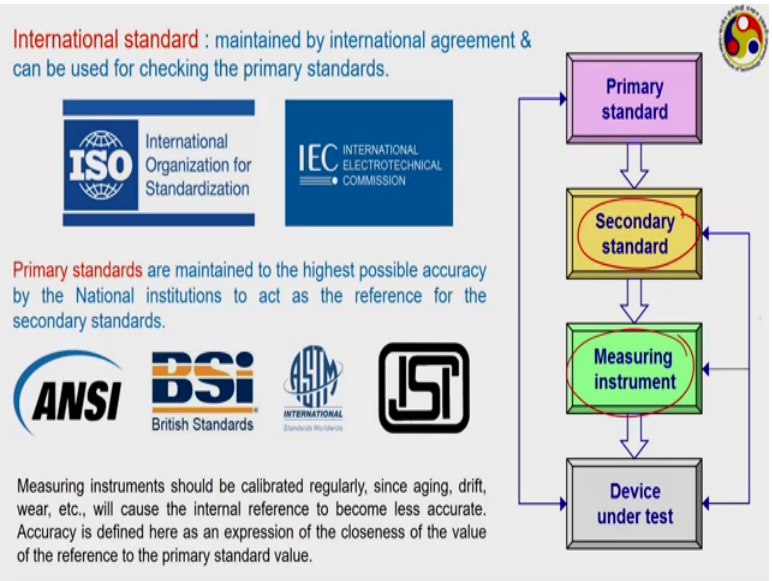

Now, there can be several kinds of standard primary secondary and also measuring or lab based standards whenever we are comparing a device for as whenever we are performing the measurement based upon the standard for measuring instrument. Then that is a secondary kind of measurement same for secondary standard, but only when we are able to compare with the primary standard we are getting much more accurate measurement.

But above the primary also there is the international standard which are maintained by international agreements and can also use for checking the primary standard like the one I have just mentioned about. There are a couple of organizations like ISO and international electro technical commission they set up these international standards. Primary standards are generally based upon the country the there are national institutions who maintain the highest possible accuracy for this primary standard to set up the reference for the secondary standards.

Every country have their own standard like NC or ASTM for US BSI says the British standard ISI for Indian standard. Whenever we are purchasing some instrument we need to check that whether that follows a standard properly or not. And even and also it is also possible that at the beginning it may not be perfectly following the standard has a very high level of accuracy. But over the period of operation years of operation it may lose the accuracy a bit because of aging drift where etcetera.

And so, time to time we may have to calibrate it back using certain kind of secondary or other tertiary standard. Like one example maybe if you want to set up the time in your mobile phone what we do either you compare this one with time for something which you trust or maybe nowadays we often use the time provided by the network provider. Now that is some kind of tertiary or even lower level of standard because them the network provider is also testing or checking of their time based upon something else.

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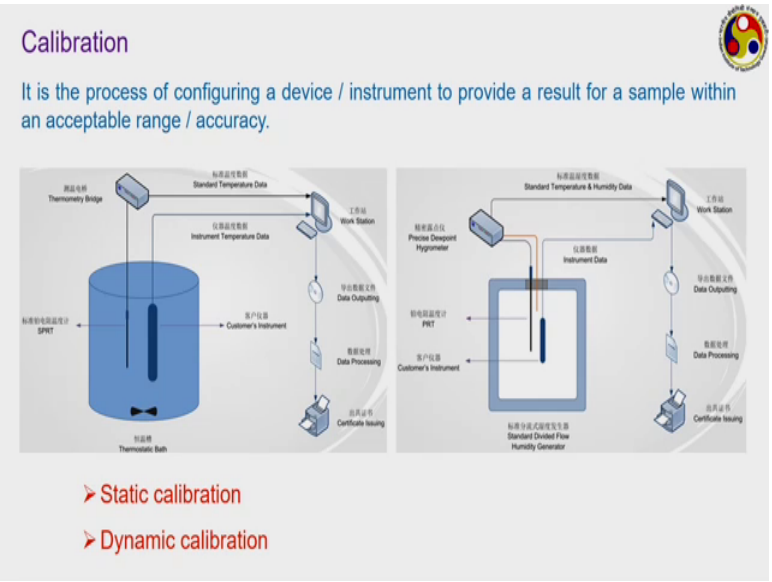

So, that can be one way we do set up these measurements. Calibration is a process of configuring or your device or instrument to provide result for a sample within an acceptable range or accuracy. So, to calibrate a device whenever you have purchasing a device or later on if we want we to get it recalibrated we compare with a standard 1 couple of examples are shown here regarding temperature and humidity measurements I shall be coming back to this topic of calibration in the next lecture and so I am not going to continue too much about this.

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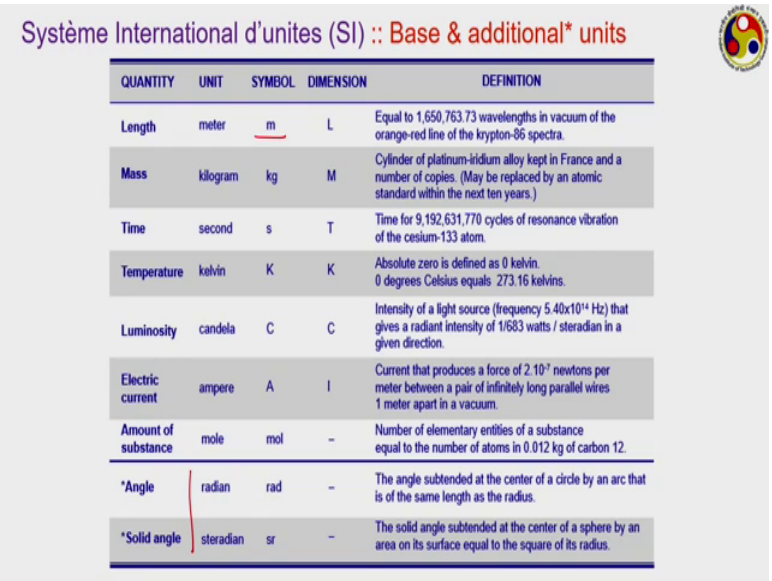

QUANTITY	UNIT	SYMBOL	DIMENSION	DEFINITION
Length	meter	m	L	Equal to 1,650,763.73 wavelengths in vacuum of the orange-red line of the krypton-86 spectra.
Mass	kilogram	kg	M	Cylinder of platinum-iridium alloy kept in France and a number of copies. (May be replaced by an atomic standard within the next ten years.)
Time	second	s	T	Time for 9,192,631,770 cycles of resonance vibration of the cesium-133 atom.
Temperature	kelvin	K	K	Absolute zero is defined as 0 kelvin. 0 degrees Celsius equals 273.16 kelvins.
Luminosity	candela	C	C	Intensity of a light source (frequency 5.40×10^{14} Hz) that gives a radiant intensity of 1/683 watts / steradian in a given direction.
Electric current	ampere	A	I	Current that produces a force of 2.10^{-7} newtons per meter between a pair of infinitely long parallel wires 1 meter apart in a vacuum.
Amount of substance	mole	mol	-	Number of elementary entities of a substance equal to the number of atoms in 0.012 kg of carbon 12.
*Angle	radian	rad	-	The angle subtended at the center of a circle by an arc that is of the same length as the radius.
*Solid angle	steradian	sr	-	The solid angle subtended at the center of a sphere by an area on its surface equal to the square of its radius.

Calibration generally can be of two types static and dynamic again I shall be talking about them in the next lecture. These are the internationally accepted standards you know as per the SI units there are 7 fundamental units and out of this 7 the length mass and time and temperature are the one that we have to use repeatedly in any kind of mechanical measurement. So, the earlier days the length of measurement or the I should say the unit of measurement which is meter was based upon a certain cylinder again kept in a standard laboratory.

But however, nowadays it is based upon the wavelength of krypton 86 mass. We have already talked about the standard for time is based upon the resonant vibration of caesium 133 atom. temperature is based upon the absolute 0 and same for the others angle. And solid angle these two are not fundamental units, but sometimes they are included as additional units. Because they do not have they cannot be derived from any of the other 7.

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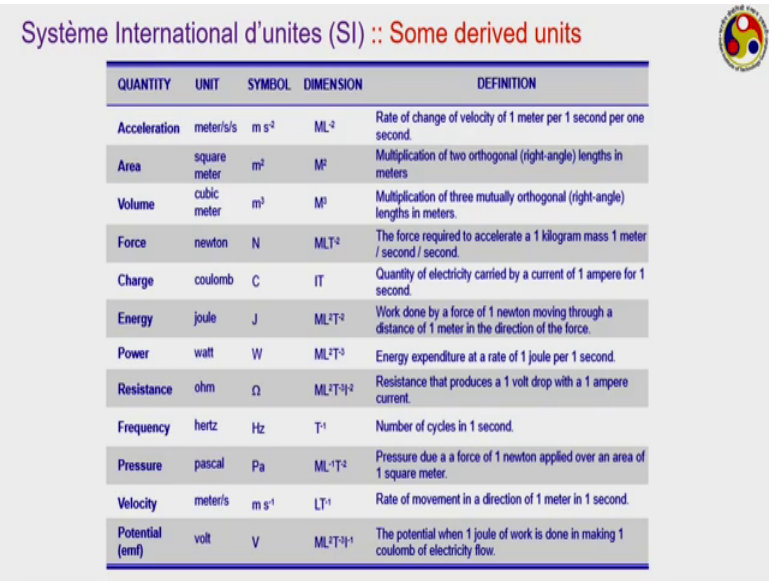

QUANTITY	UNIT	SYMBOL	DIMENSION	DEFINITION
Acceleration	meter/s/s	$m\,s^{-2}$	ML^{-2}	Rate of change of velocity of 1 meter per 1 second per one second.
Area	square meter	m^2	M^2	Multiplication of two orthogonal (right-angle) lengths in meters
Volume	cubic meter	m^3	M^3	Multiplication of three mutually orthogonal (right-angle) lengths in meters.
Force	newton	N	MLT^{-2}	The force required to accelerate a 1 kilogram mass 1 meter / second / second.
Charge	coulomb	C	IT	Quantity of electricity carried by a current of 1 ampere for 1 second.
Energy	joule	J	ML^2T^{-2}	Work done by a force of 1 newton moving through a distance of 1 meter in the direction of the force.
Power	watt	W	ML^2T^{-3}	Energy expenditure at a rate of 1 joule per 1 second.
Resistance	ohm	Ω	$ML^2T^{-3}I^{-2}$	Resistance that produces a 1 volt drop with a 1 ampere current.
Frequency	hertz	Hz	T^{-1}	Number of cycles in 1 second.
Pressure	pascal	Pa	$ML^{-1}T^{-2}$	Pressure due a a force of 1 newton applied over an area of 1 square meter.
Velocity	meter/s	$m\,s^{-1}$	LT^{-1}	Rate of movement in a direction of 1 meter in 1 second.
Potential (emf)	volt	V	$ML^2T^{-3}I^{-1}$	The potential when 1 joule of work is done in making 1 coulomb of electricity flow.

These are certain common derived units like acceleration area, volume, force, resistance, frequency, pressure, velocity, which can all be all be derived by combining one or two or more of the fundamental units.

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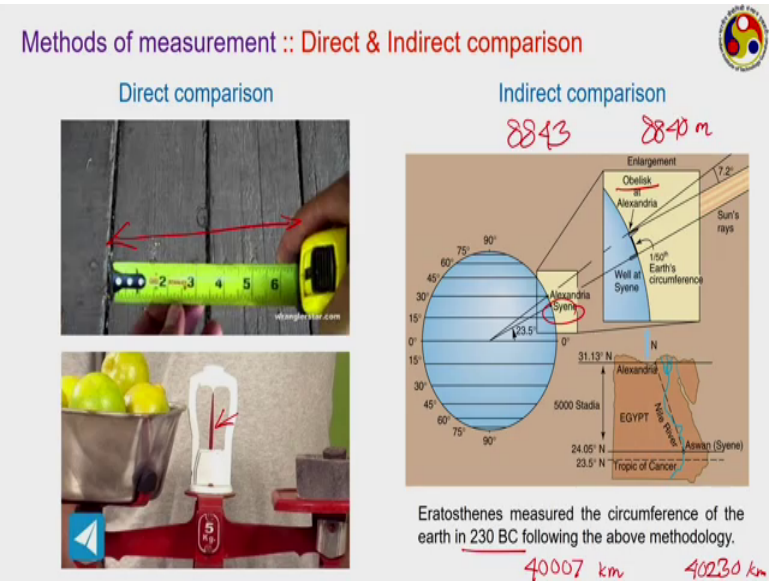

Now, methods of measurement; measurement can be classified into several categories. The first is direct and indirect; direct means when we are able to take our measuring tool to the point where you are going to perform the measurement like mirroring the length of this particular section we are taking a measuring tape and directly drawing a

measurement or this particular one we want to measure the mass of some fruits. So, we are putting it on a balance on one side you have the fruit which your object on the other side you have some standard weight and when this particular indicator touches 0 we know that the mass are equal from there we are making measurement.

So, this is a direct measurement where we are able to compare the standard and the measurement directly. But there is also indirect measurement and indirect measurement can be much more powerful one a very good example can be this. The measurement of this circumference of earth performed by Eratosthenes in 230 BC focus on this we are talking about 230BC two more than 2000 and 1100 years from now. And I should know 200 200 years and what he did he compared he observed that on the day of summer saltys that is June 21 one particular whale at this sign does not prove great any shadow. And sign was about 800 kilometres from an Obelix at Alexandria that is this one about 800 kilometres from them.

So, he measured the arc angle using the principle of trigonometry and from there he got a measurement about this circumference of the earth as for the modern technology the pole to pole distance has been found to be something like 40007 kilometre. Now what measurement Eratosthenes gave his value was; 40230 230 kilometre. How much is the difference almost negligible and this measurement he did 2200 years back that is the power of indirect comparison. There are several others like you definitely must have heard about the name of the great mathematician Radhanath Sikdar. What he did? He was the first person to scale or to measure the height of Mount Everest that time it used to be called the peak number 15 in 1852 he measured the height of Everest.

And gave it a value of as per his measurement it was measured to be 8840 meter how much is this as per the present measurement it is said to be 8840 meter, but there is debate about the ice cap that is on top of this. A measurement done by Chinese agency in 2005 showed it to be about 8843 meter. Again the you can see the power of indirect measurement and not only for such large scale even for smaller scale like measuring the mass of an atom missing the mass of an electron the charge of the proton we all use or based upon the direct measurement and there are innumerable other examples we can find and you can also maybe think of a few examples.

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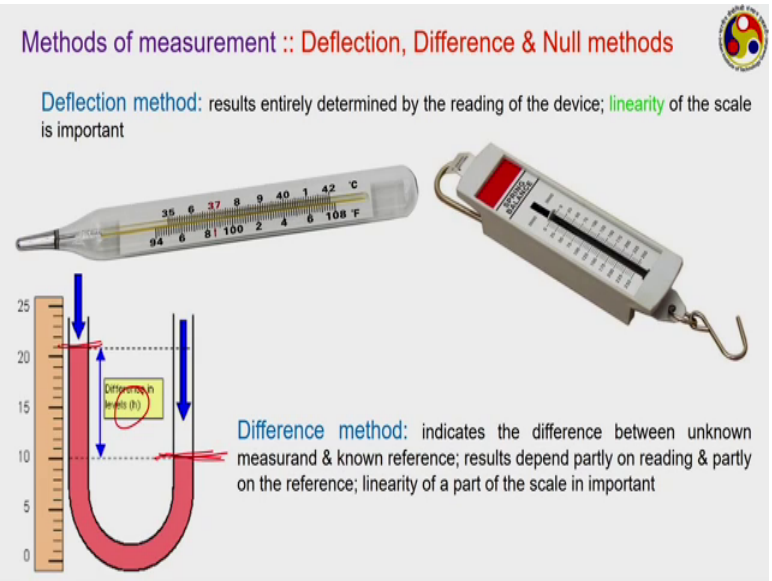

The other kind of classification can be deflection difference and null methods. What are this? Deflection is what the result is entirely based upon the reading on the device like this one. While we are measuring body temperature using a clinical thermometer we know that the fluid which is inside the capillarity tube commonly mercury that is moving inside the tube. Like here you can see on this scale I think the picture is not clearly shown it is showing a reading something like this for say it has expanded.

And the tip of this liquid column has reached somewhere here then directly from the scale we can get the measurement. So, here the measuring instrument itself is showing some kind of deflection from it is initial position or base position and the amount of deflection is giving you the final value of the measurand. And another common example can be the spring balance initially it is showing the 0 reading, but whenever you are putting something on this scale. Then because of the it is putting some kind of force on the spring and accordingly this indicator is coming down to indicate certain value somewhere here which is giving us a measure of the weight of whatever we are putting in this as the measurand.

So, this is the deflection method linearity of the scale is important I have made this term linearity in green because in the next lecture we are going to talk about this is one of the properties of the measuring systems. Difference method indicates the difference between the unknown measurand. And known reference there is a known reference and there will

be some kind of difference between the known reference and the measurand. So, the result will depend partly on the reading.

And partly on the choice of your reference like the manometer we have already seen one example earlier here we have a known pressure which is acting as a reference. And now here we are getting this much of deflection which is this h h represent the deflection and then we have the reference here combination of these two is going to give you the final pressure which is acting at this particular point or vice versa if you take this one as reference then we are going to get the are reading at this particular point. So, here also the linearity of the scale is important.

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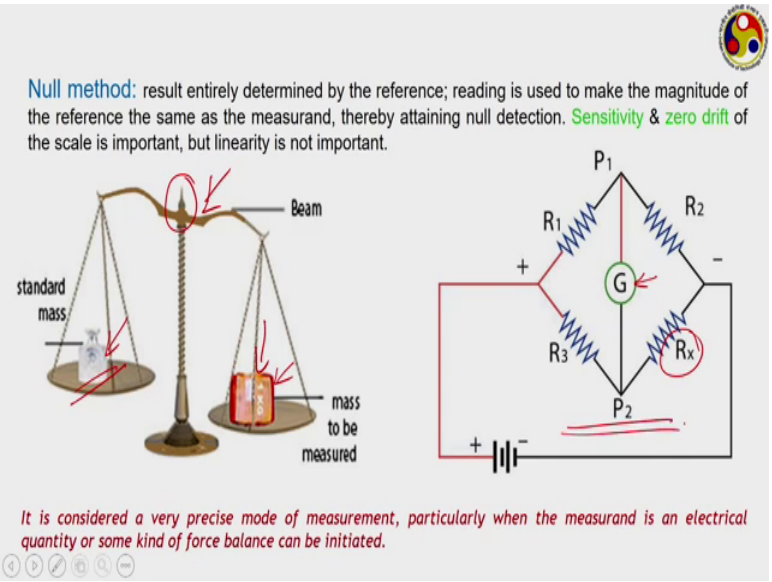

The next one is null, null method where entirely the measurement is based upon reference the best example can be such kind of weighing balance here we put the put the measurand on one side here. And on the other side we keep on adding standard mass and we keep on waiting till the indicator which may be somewhere here which shows a 0 value a null value. That means, whatever deflection of the indicator has been caused his measurand that has been negated by the standard mass.

And when we can able to achieve that then we can say that whatever standard mass that we have added on this particular arm is equal to the mass of the measurand null is probably the most common kind of measurand not only this one. Another very common example is a witch stone which you all know about the principle like here we have four

resistance; one of them is unknown this one maybe the unknown one other three are known values. So, we keep on changing or adjusting their values till you get a 0 reading from this galvanometer. So, we negated the effect of this particular resistance and accordingly we get a measurement from this null method is considered to be a very very precise method of measurement.

But I am not talking about accurate because the accuracy of measurement will depend upon the accuracy with which you are measuring this standard if your choice of standard is wrong like suppose you have purchased some quantity of food some quantity of fruit and you are getting that measured by the shopkeeper. Now the shopkeeper is showing that it is showing a null kind of measurement with an with a weight or with a body of 1 kg mass, but it is written 1 kg there if that itself is not 1 kg say if that is 970 gram then your measurand is also 970 gram. So, it is precisely giving a measurement of 970 gram but as there is inaccuracy in the choice of standard itself.

So, there may be inaccuracy in the final measurement also, but it is generally very very precise one, particularly when the measurement is measurand some kind of electrical quantity or certain kind of force balance we are trying to do like in this case we are doing a force balance and here we are measuring an electrical quantity using the galvanometer.

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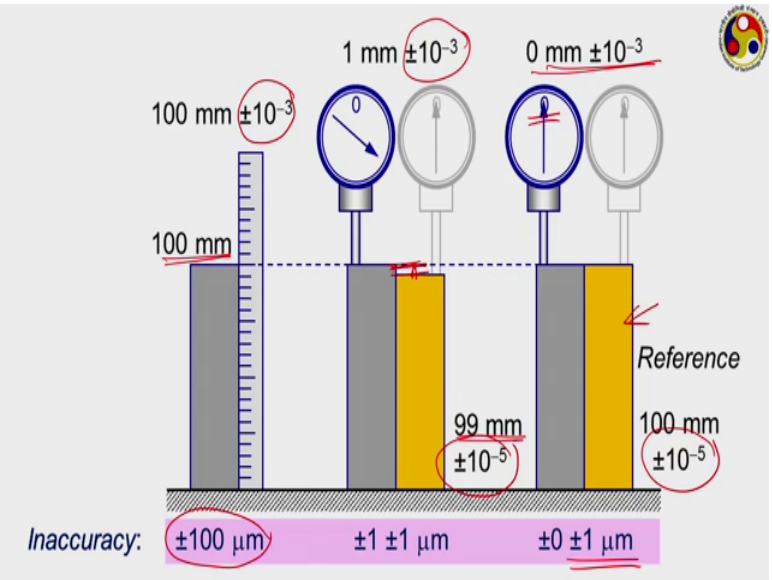

An example here we are trying to measure the length of a bar which is supposed to be 100 mm, in case of first case we are taking it in contact with a scale. And the deflection

of a scale is giving you the measurement. So, we have to get the reading from the scale itself and you have a possibility of making plus minus 100 micron kind of error because the scale is shown to have an error of 10 to the power minus 3 of the reading. Again what we refer by this I shall be coming to the 3rd lecture for the moment you take that this 10 to the power minus 3 indicates an error of the reading. So, 10 to the power minus 3 times 100 millimetre is 100 microns.

So, there may be an error of hundred micron this is the difference method here we already have a standard whose length is 9 mm. And so when we come in and take the measurand and the standard in contact with each other there is only this all tiny gap left. So, your indicator will only indicate this amount of gap which is supposed to be 1 mm. But depending on the indicator we may have this amount of error coming in and also the measurand itself may have some error like 10 to the power minus 5 as in this example. So, we can have one micrometre coming from here and also about one micrometre coming from here and third one where we keep on adjusting the reference this is the reference till we get a null reading.

So, we do not fix up the height of the standard initially rather we keep on changing the height of the standard till we get 0 deflection on this reading. So, we are not going to get any kind of error from this deflection, but the choice of or the error that is present in your reference itself may show you certain kind of error which is here. And 1 micron in this particular case which is 10 to the power minus 5 times of 100 millimetre which is your reference. But no error is coming from this, but like it was mentioned in the previous slide certain properties like 0 drift etcetera may be important which you shall be discussing in the next lecture.

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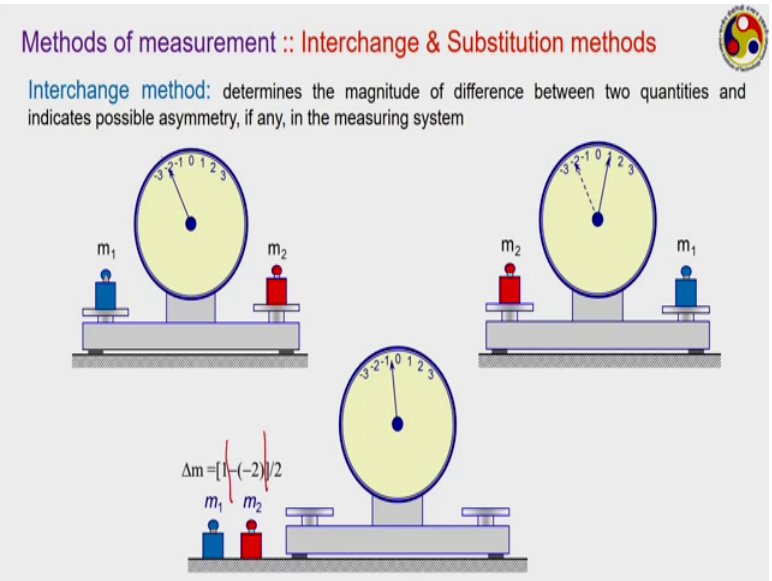

Another type of a method of measurement can be the interchange and substitution method what is interchange method it determines the magnitude of difference between two quantities and indicates possible asymmetry. If anything is present in a measuring system itself like here we have two arms of the measuring system. So, we are putting 2 say 2 mass m 1 on 1 side m 2 on the other side and is showing a deflection of minus 2 on the scale. Now we interchange them, now we m two is on the left m 1 on the right.

And we can see now the indicator is showing plus one on the right hand side, but what it should have been if this indicator is a correct one. If your measuring device is a correct one there is a difference of two unit between m 1 and m 2 and m 2 is heavier compared to this red one is heavier that is why there is a minus 2 reading in m 1 or let us take the other forget the minus let us say m one is heavier and that is why it is showing a two unit of deflation.

But when you have taken this side be showing only one unit of deflection; that means, there is some kind of error present in the measurement system itself of course, these 2 mass m1 and m2 are not equal because there is some deflection. But the instrument itself is also showing some kind of error then how to get the final amount value of final value of deflection between them to take the mean between the two the mean of the absolute value of this that is the absolute value of minus 2. We are taking and the absolute value

of one we are taking and the average of that is giving you the difference between the two and also giving us some indication about this like here none of the mass are present.

But it is showing some kind of inclination towards the left which indicates it is 0 very common example of with all those weight measuring machine if you go to measure the weight. And if the indicator of the weight measuring machine dial is already at 5 then whatever final reading you are going to get you have to subtract 5 from there that is a kind of 0 error. Again I shall be talking about that later, but this interchange method can very well give you some idea about the asymmetry or inaccuracy that is present in the measuring system itself.

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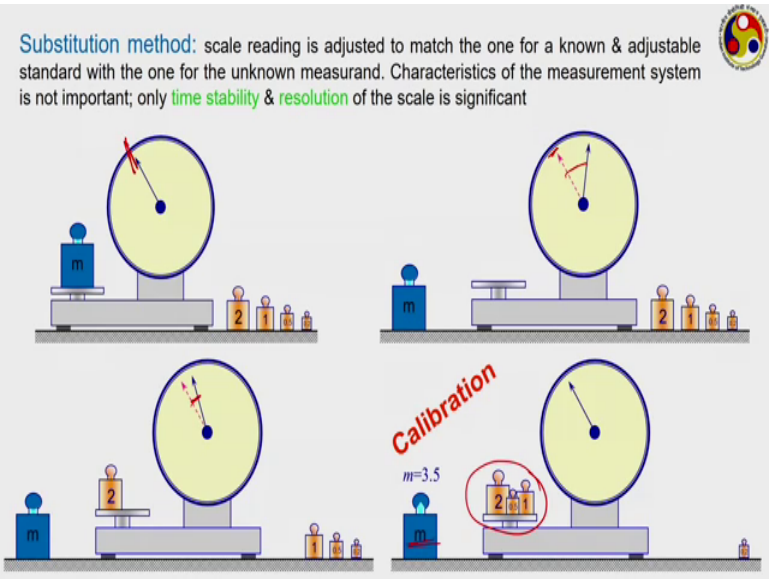

Other is the substitution method in the substitution method here the first we put the measurand on the dial and get the reading. So, this is the reading that you are getting and noting the reading. And now we remove the measurand and we keep on adding some standard. So, we have keep the value of the measurand of the scale position of the measurand. And then we are keeping on adding the standard as we are adding the standard it keeps on changing and keep on waiting till it comes back to the original position. Here still we have some difference of this much we have added something.

So, still there is some difference we need to add some more standard. And finally here it gives us some kind of null deflection means indicators come back to the initial position which we have fixed up with respect to the measurand. And so this is we can get the idea

about the mass of this one by adding up the values of all these standards this is again a very common method of measurement the substitution and also the substitutions are probably the most common method of calibrating any instrument.

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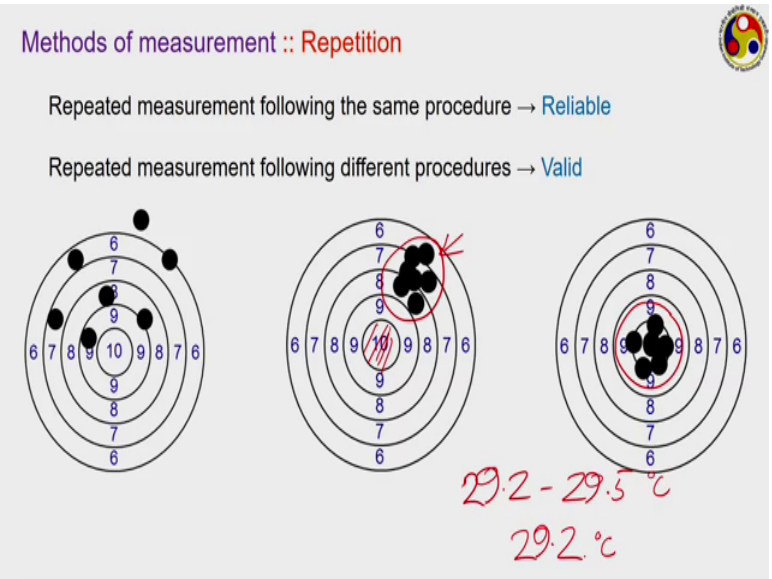

And finally, another this truly speaking is not a method of measurement. But repeating the measurement is sometimes very very important one because if we repeat the measurement and or if I should say we are trying to measure particular quantity. We follow a particular procedure and keep on repeating the procedure, if we do not get the same rating reading every time then your measurement is not reliable. Like in this case I have taken the diagrams from the bulls eye view of a shooter you can see in the first case every shooting is landing in a different position every bullet is landing in a different position which represent very very inaccurate kind of performance by the shooter.

Whereas, in the second case there is a very nice group within a very small zone all the bullets have hit. So, it is a very reliable measurement it is giving, but it still may not be accurate one because you can see in this diagram our target was to hit this particular zone, but actually it is quite a bit away from this. So, to indicate and if our measurement is for an unknown quantity. Then we do not know we from this we know that our instrument is giving a reliable reading only by repeated experimentation. But whether it is accurate or not to know that we need to change the instrument follow maybe a different procedure. And see whether we are getting the same value or not a correct one

should be something like this. So, by changing the like suppose you are measuring temperature with 1 thermometer by repeated readings it is giving you a value something in the range of 29.2 to 29 0.5 degree Celsius.

So, there are 10 readings you have taken and all have come out in this small range. So, it is a quite reliable measurement that you are getting. But now you change the thermometer take another one and if that gives you 21.2 degree Celsius. Then there has to be some problem with either with the previous one or the new one, but if this new thermometer is also giving you a value of say 21.2 then the previous one was also correct. So, repeating the experimentation with the same instrument and also with if possible with the different instrument is also a must in the process of measurement.

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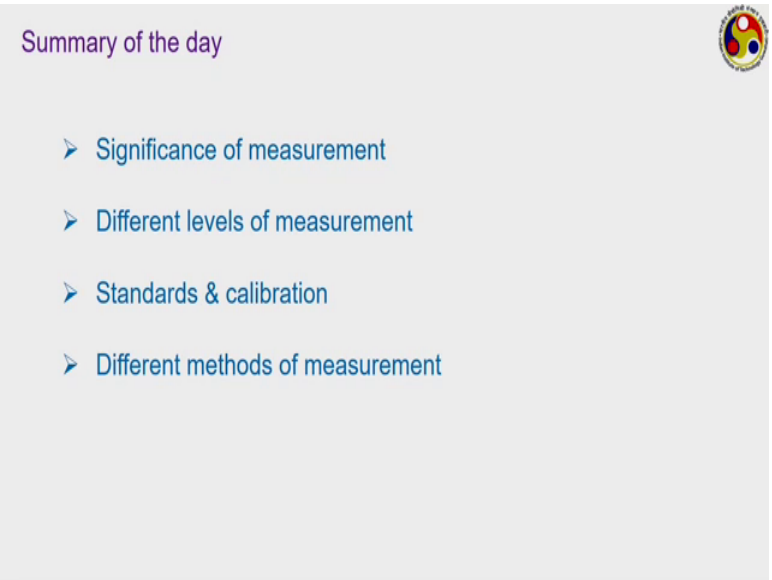

So, that takes us to the end of the day to summarize whatever we have done we have talked about the significance of measurement. We have discussed why measurement is required and a few fundamental aspects of measurement like different levels of measurement you have seen there are four different levels each one keeps on adding some to the previous one and the ratio level of measurement is the best one. But there are several other instruments which uses the equal interval or interval level of measurements also then we have talked about the standard and calibration.

I shall be coming back again in the next lecture and finally, we have talked about different methods of measurement. So, that takes us to the end of today's lecture we shall

be continuing this module 1. In the next lecture we shall be talking about the general structure of a measurement system the different kinds of inputs the prop and also different kinds of properties like some terms I mentioned linearity 0 drift etcetera. We shall be mentioning about those.

So, thanks for your attention for the day thank you very much and see you in the next lecture.