Probability Methods in Civil Engineering

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Lecture No. # 03

Set Theory and Set Operations

Hello dear and welcome to the second lecture of our second module random events. In today's lecture, we will cover set theory and set operations, which is very important in the understanding of the concept of probability theory. So in this class, we will know the concept of set and different set operation, which will be useful to describe the different probability to different set and subset of a outcome of particular experiment.

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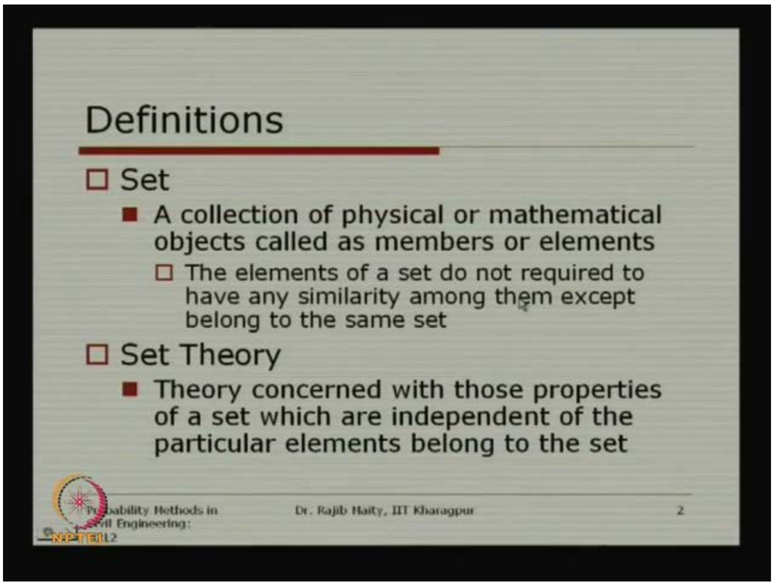

First we will know the definition of the set and set theory, basically a set is a collection of physical or mathematical objects called as members or elements. So the elements of a set do not require to have any similarity among them except that they belongs to the same set. So, basically a set if we want to want to define that it is a collection of any a collection of a particular group of elements and those elements can be physical or mathematical in terms of different outcome of a particular experiment, if we think in the context of our probability theory.

Now the set theory says the theory concerned with those properties of a set, which are independent of the particular element belong to the set, so when you say that set theory those theories generally applicable to the whole set, it is not related to a particular element of a set. So, the overall the set what are the different operations that we can do, what are the different theories that is applicable to the full set, and that consist that is, we call as set theory.

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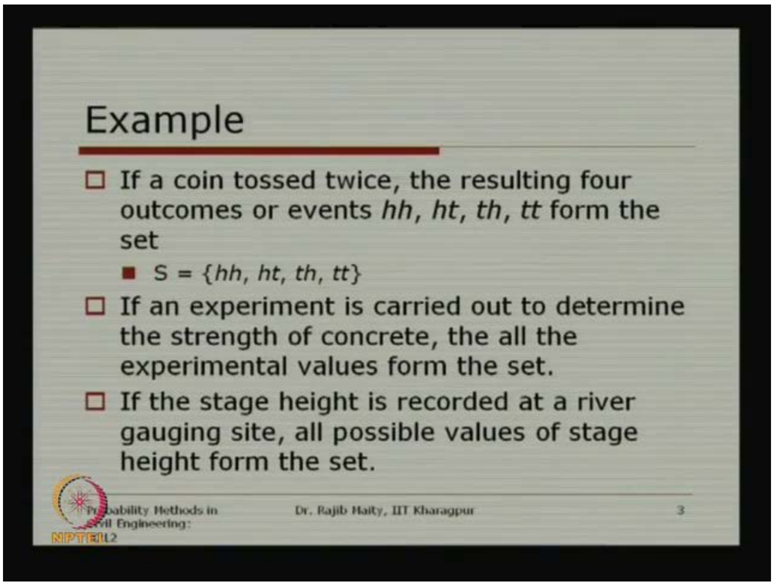

So, with this if we see that different examples, so if we start with the that our classical example one for example, if we take a coin and if it is tossed twice, then the outcome of this experiment can be of a either the first and second both are head or head tail or the first one is tail and second one is head or both are tail, so the outcome of this events that is the full all the collections of this experiment is one set. In an experiment is if a if an experiment is carried out to determine the strength of concrete in particularly in the civil engineering, then all the experimental values. Generally they form A set in the other example of the stage height generally, we measure the stage height at a river gauging site there if we take that the river gauging site, if we take the stage height at a particular gauging site, then the all possible values of the stage height form the set.

So, here you can see that these things can have any value depending on the physical range of the strength of the concrete depending on various factors its water cement ratio or the time and type of curing and all these things it can take any values. For this type of set, this we can say whenever we are saying that the stage height, this is generally called one side it is bounded by 0, so physical or in the mathematically, it can take any value starting from 0 to the class infinity.

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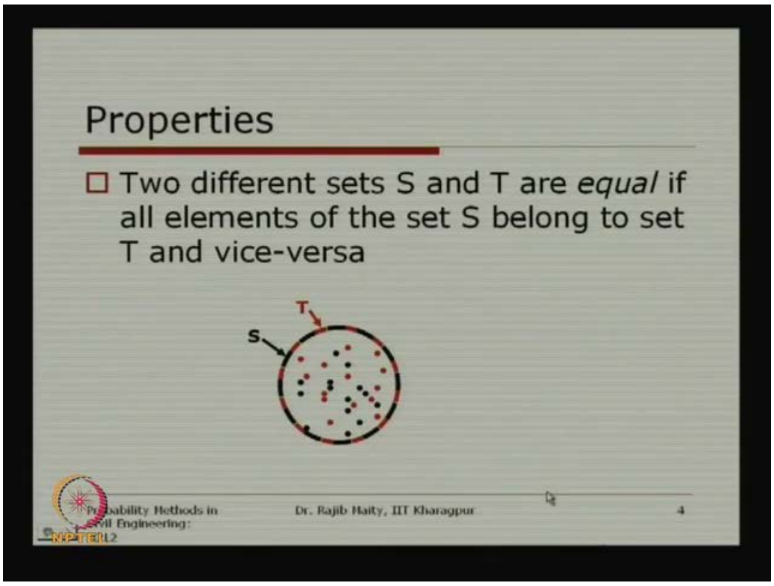

So, all this outcome if we take a total this is generally this form, generally a set there are different properties that will see now one after another, the first thing is that when we say the both the sets are equal. So two sets are we generally say these are equal if all the elements of one set belong to the other set and vice-versa. Here in this pictorial representation, there are two sets are there; one is one is drawn by the red circle and another one is drawn by the black circle, if see that these are exactly sums of whatever the entries that belongs to the red set, there are some red dots and the black dots and also there are some… So, all theses dots belong to both the set S as well as set T. Now, so we can say that this set S and set T are equal. In the example of the throwing a dice, it has having the six different output, now if I say the one set is even and the outcome is even number and if in other words, if I say the outcome consists of 2, 4 and 6, then we can say that these two sets are equal.

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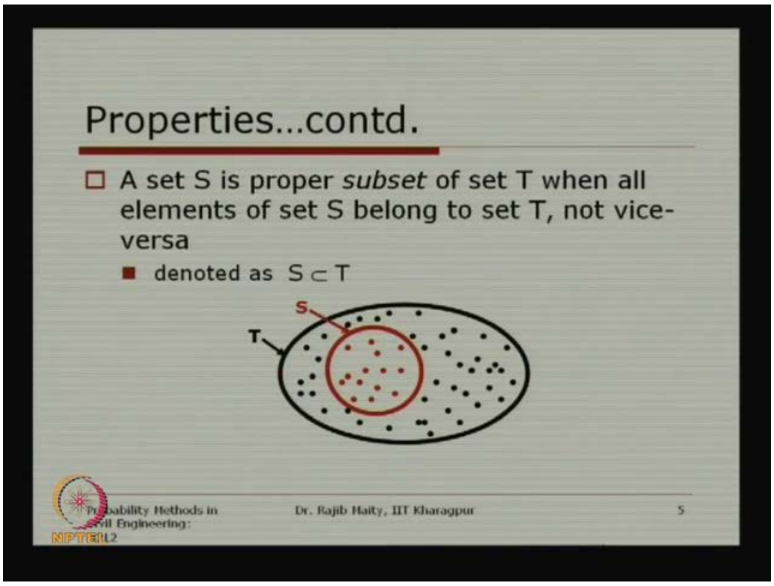

This is very important which is known as the subset; a set S is a proper subset of another set if we can designate that T when we say that all the elements of this set T belongs to the former one that is S, but the opposite is not true that is which is the vice versa is not correct. So if you see this pictorial representation this the bigger ellipse is the T set and inside this there is another set, which is shown in a red circle, so this S belongs to this T, so this S is known as the subset of subset of this the larger set T.

So, in the example of the river gauging site if I say that the extreme values of the stage height, then I can say that if I say that all the stage height that is above say 10 meter or I can say that another set, which takes the all possible values. So, the all possible values means that can take any value from 0 to whatever the physical maximum in available height in the historical record or it can be even higher than that. And another set is that the just extreme value which I put a threshold of the 10 meter, then I can say that the threshold, which is more than 10 meter is that is a subset is a subset of the full set, which can take any value from 0 to mathematically plus infinity.

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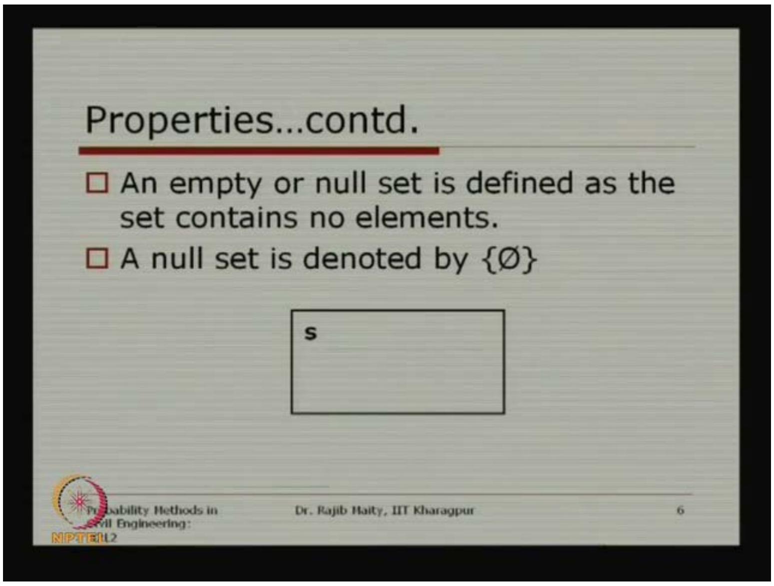

The second thing that is a known as a null set, when we say that there is a particular set, which does not have any element in it, then we say that this is a null set and it is defined as that when the set contains no element and this is denoted by this kind of symbol you can see here that there is set, where there is no element then we can say that this is a null set. In the probability concept, we can say that this null set is generally is a set that is the impossible set that is impossible outcome; for example, if I say that the strength of concrete, then if I say some value which is negative, then we can say this is an impossible event and this is this set is a is a null set, which does not have any entry, which is which belongs to then negative value less than 0.

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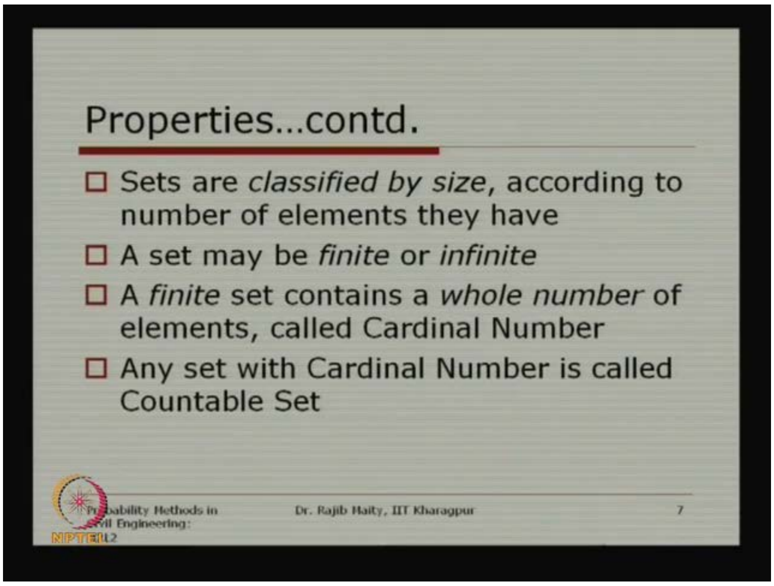

Generally the sets are classified by its size according to the number of elements that they are having a set a may be finite or infinite, a finite set consists of a whole number of elements, which is known as the cardinal number. Now if any set that is having the all the number with the cardinal numbers, numbers is called the countable set; and infinite set generally infinite set, when we cannot count or the number of elements that belongs to is infinite or sometimes the another term is used that is called the countably infinite. It can be countable, but but it can be infinite in number those set those size of set is known as countable infinite set. So, these are all the basic concept that is will be useful to understand the other properties and the operations of set.

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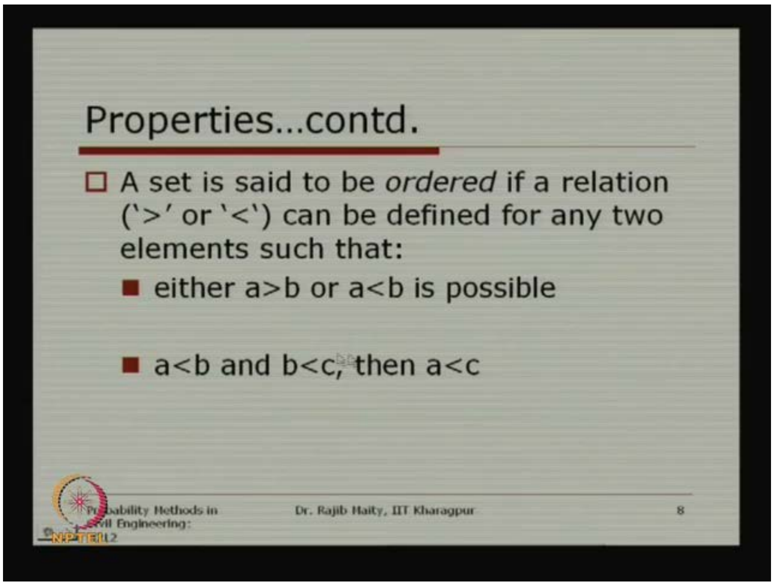

The second one, another important thing is ordered if A set is generally said to be ordered, if a relation like the greater than or less than can be defined for any two elements of the set. For example, if I say if I take two elements a and b, I can say that a is greater than b or a is less than b is possible, then this kind of set is known as the ordered set. We can even conclude that if we say that a is less than b, and b is less than c, then I can say that the element a is less than element c, so this kind of set is known as the ordered set.

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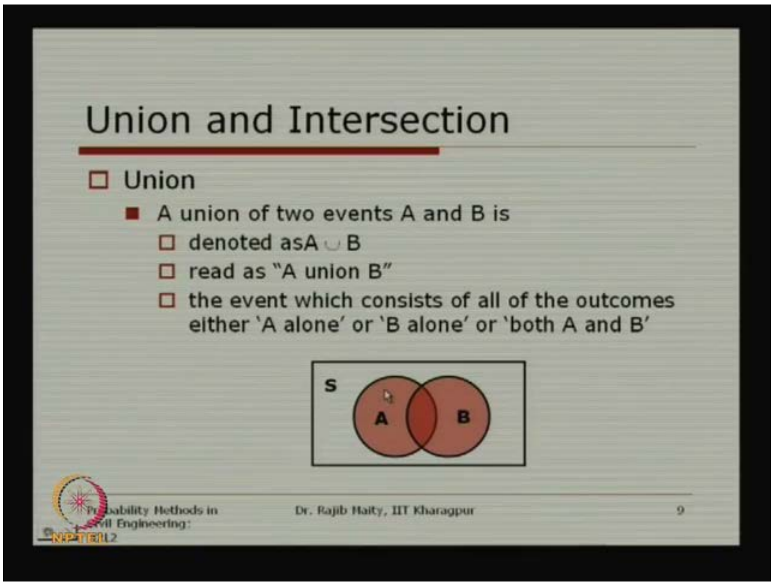

These two are two operations, which is very important and frequently used these are known as one is union and another one is the intersection, this concepts are very important to understand the later part of this of this class. First, we take this union a union of two events that is A and B, here you can see that this is your, this is your full set; this is your full sample space and in this space, there are two events one is this the left hand side circle and another one is the right hand side circle, which is denoted as B and the earlier one denoted as A. So, this two are events in the in the sample space S; now the union of A and B is generally denoted as A this symbol B, this is this is generally read as the A union B; this A union B consist of all the outcomes that is either in a alone or B alone or both in A and B. So you can see this three regions, where I am pointing now this area is belongs to A only, this area belongs to the B only, and this in between belongs to both A and B. So if I say that A union B, then this area which is highlighted in red, this area in total is known as the A union B.

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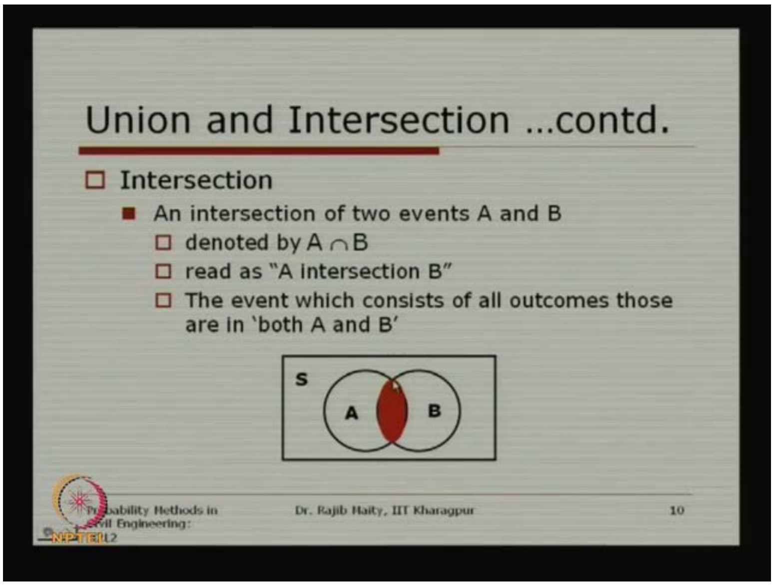

On the other hand, if I say the intersection again this two events are defined here one is and another one is B, and this is its intersection is denoted as this symbol B, and it is read as the A intersection B. So, we call that intersection is defined as all the outcomes, those are in both A and B, so it must be both in A and B. So obviously the highlighted area, the red highlighted area is known as the intersection between A and B. So once again the union is the total area that consist of either B or A or both A and B, that is the union; and intersection means, it is both on A and B.

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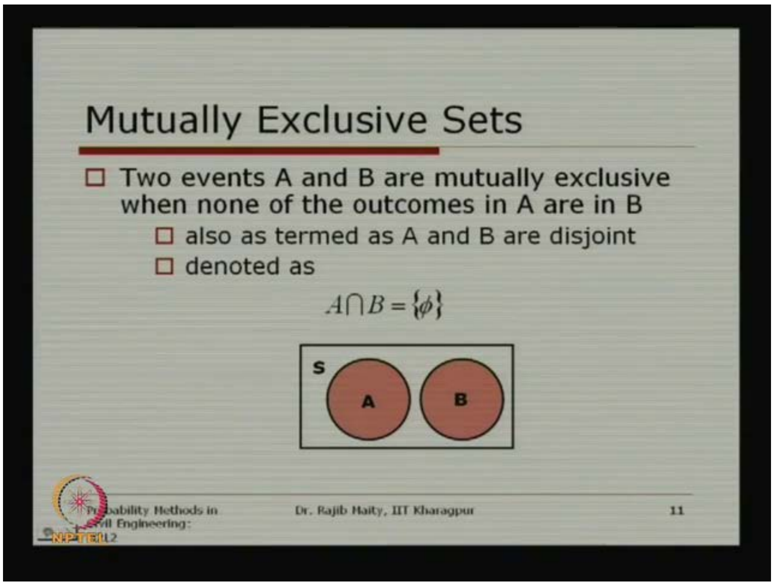

There are other few concepts that is also useful here one is the mutually exclusive set, this mutually exclusive set between two events A and B, we can call that this A and B are mutually exclusive, when no outcome, no element in A are in B and of course vise versa. So there is no overlap between this two these two sets. So if we say that there is no overlap between these two sets that means. If I take the intersection between A and B, now you know this symbol is an intersection that means in this intersection there is intersection A is a null event, where there is no element exist in this part.

So you can say that if this two are completely separated, there is no overlap area, these two events known as the mutually exclusive event in the in the in the example of a example of a throwing a dice. If I say that one set consist of all the even numbers and another set consist of all the odd numbers, then you can easily say that there is no intersection between these two events, and so all the set consist of the even number and the set consist of the odd number are mutually exclusive sets.

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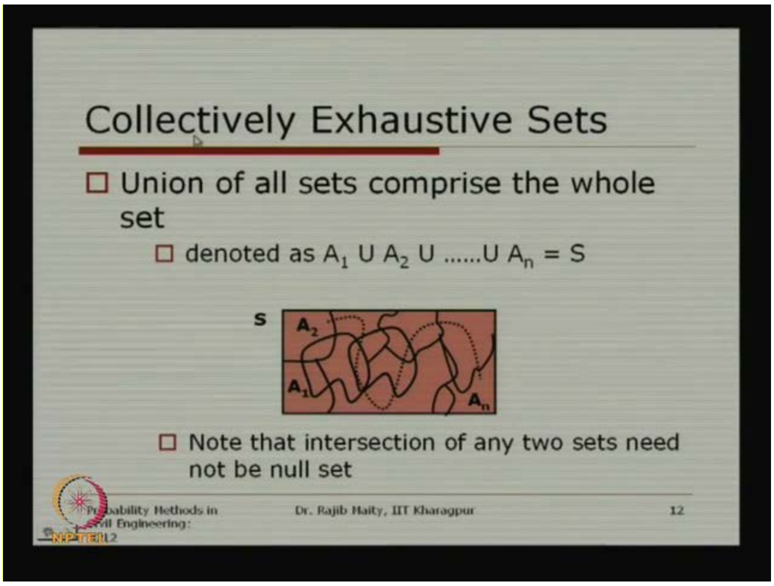

There is another very important and very frequently we use the concept, which is known as the collectively exhaustive sets. Now the collectively exhaustive sets means, when I take some subsets or some events or some sets; and if I take the union of all this events then I can say, if that if the union of this sets comprise the whole set, whole set means that whole sample space if it consist of now you can see that there are few subsets has defined here say for example, this area is your A 1, this area is your a A 2, in this way it is going on, and there are some subsets like this.

Ultimately, if I take the union then obviously, the full union consists of this whole sided, red sided area, so this whole red sided area is nothing but you have the full sample space. Here one thing is important to note that the intersection of any two sets need not be null sets, so you can see that this a A 1 and A 2 the intersection is null but this A 1 and if I say that this is another set which is a A 3, so there are some intersection point. So we are not considering the intersection point here we are just considering the union. So, if I can somehow say that all this unions consist of the full set, then I can say that this is a this is a this is collectively exhaustive set. In the example of a throwing a dice if I say that one event is less than 4 and another event is greater than two, and if I take the union of this two obviously, the union will consist of all possible outcomes starting from 1 to 6. So the two sets, which is that less than 4 and greater than two, there may be some intersection but if I take the union of this 2, it consist of 4 possible sets. So, these two events are mutually exclusive sets.

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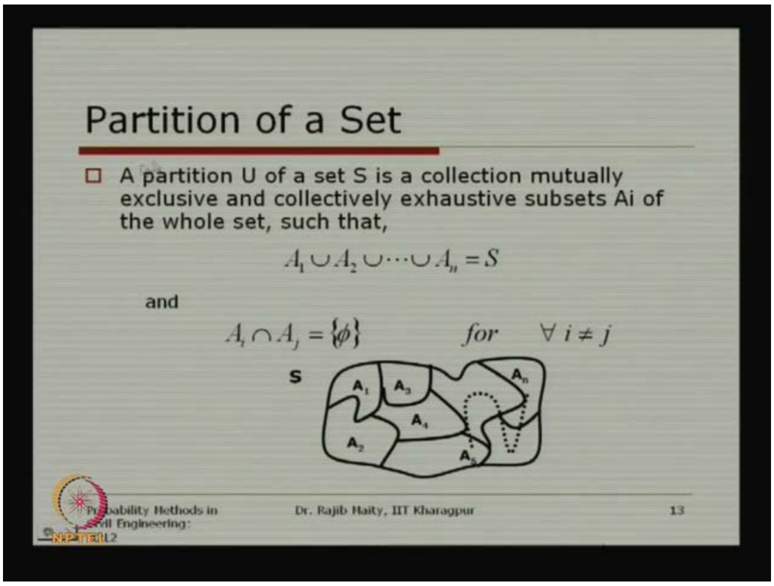

Then the partition of A set. Now this partition of a set suppose that we have one set in hand, and I want to make it partition. Here I just make this is a the another subset A 1, this is A 2 and in this way it is going on an up to n, so n number subsets are there in such a way that there are two conditions must be satisfied.

The first condition is that if I take the union of all the sets, it should consist of the full set, which is here shown as S, the full set. And if I take the intersection of any sets as long as i is not equal to j, then this intersection A i intersection A j should be a null set. If see here no events are intersecting each other, so the intersection between in any two event any two subset is the null set, then we can say that this S is partition by A 1 A 2 A 3 up to A n. So if partition U of the set S is the collection of collection of that will be one word of the collection of mutually exclusive and collectively exhaustive. So, this is a new word again we will just explain it in a moment.

So the mutually exclusive this mutually exclusive means, all this unions are the are consist of this full set, again mutual exclusive and collectively exhaustive subset are A i, A i is of the whole set such that as I told there are two conditions one is that A 1 to A 2 if I A 1 to A n, if I take the union of all the set it consist of the full one and any two set in the section is 0. So in this way if satisfying this two condition, if we can make the if we if we sub divide the sets, then this is the this is known as the known as the partition of a set.

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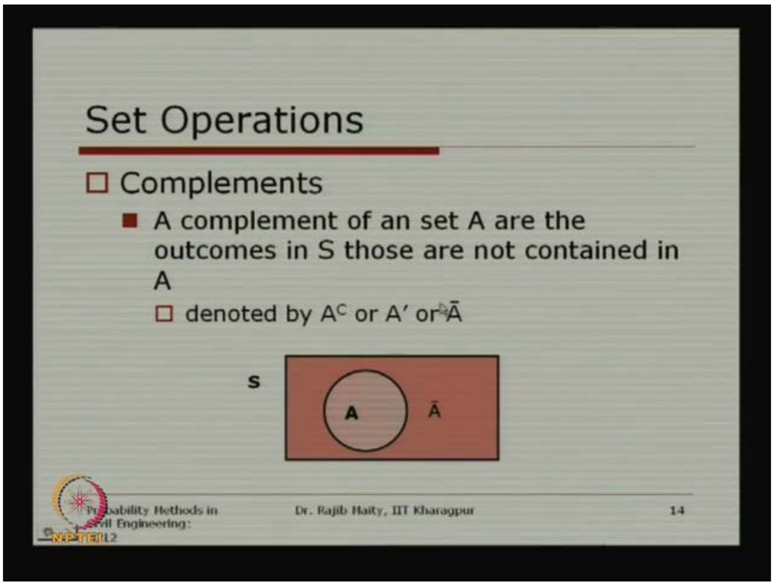

Now, the set operations; there are different set operations; the first thing is the complement. A complement of an set A are the outcome in S, those are not contained in A. So, suppose that this is your the full sample space A, and there is one event A. So, this is your event the complement of A is the area is the set, which is not belongs to A. So, if

I say that the even numbers of throwing a dice experiment the if the even number consist of one event, then the complement of this set is the odd number of the outcome.

So, one thing is very important to note here is that if I take the union of A set and its complement then we get the full set full feasible set, which is S. This complement is generally denoted by either A c or A prime or A bar, so all this notations are just a notation are different, but these are all the meaning are all for same the complements of A particular set. In this class, we will use this concept, which is A bar to denote that which is the complement of a particular set.

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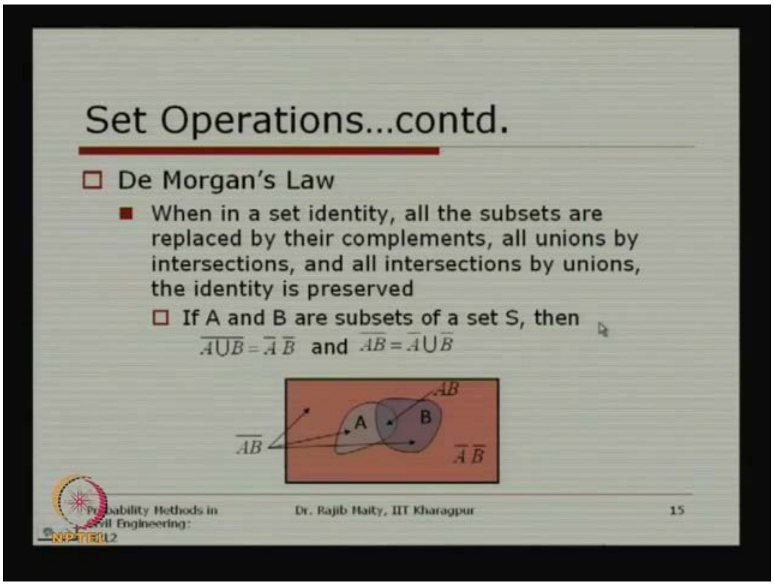

Another set operation, which falls on this De Morgan's law; before I go to this, I should tell that this unions and intersections are also the also the different set operation, which is also very important that just it is covered and the complements also you covered, and using this two things we will now explain a very important law which is known as the De Morgan's law and that is very helpful for different kinds of operations on different sets.

So, this is De Morgan's law; when in a set identity, all the subsets are replaced by their complements, all unions by intersection and all intersections by unions, the identity is preserved. May be when I am just telling this one it may not be very communicable, but we will just explain it what all these things means. Before that just look at this diagram, where there are two sets one is A and another one is B, and if we just tell once again the recapitulate what just now we have seen. So this is you're a, this area is your B, so we know that this is the this in between the intersection between this area, which is is little bit gray looking this is the A intersection B. Here when we write that A B side by side it indicates that this is the intersection; and when we write this symbol, this is generally this is generally the union. So, this area is your A intersection B; now so if I say this pink area around this one, then it is A complement intersection B complement.

So what is A complement here? So, whatever the set that is that we can see here outside of this area is your A complement, and here it is B, and outside of B is your B complement. Now all this outside area then outside B that is the complement B and complement A, if we take the intersection between these two, then only these area where my curser is moving now, only this area is your A intersection as A complement intersection B complement.

Now if I say that A B complement A intersection B that complement, then it consist of this set this area as well as this area, which is not in this intersection but the rest of this a and rest of this B, which is not in this one. So this understanding of these two that is A complement intersection B complement and A intersection B that complement is important. So, in this A intersection B complement consist of this pink area as well as this A area apart from this intersection and this B area not belonging to this intersection; these three area consist of A intersection B complement and only this outside area which is not in A, not in B, not in A and B, that is that A complement intersection B complement.

Now if we know these three area, then we can just appreciate these two relationship just you can see that if A and B are the subsets of A set S, then A union B complement; so A union B complement means, this a first of all we will see, where is the A union B, this A union B is nothing but this area and its complement means, this area what just now I explain, which is nothing but here that A complement intersection B complement, so this relationship. We can show it pictorially similarly, if I say that A intersection B, then the A intersection B is nothing but only this area now if I take the complement of A intersection B, which is shown by this bar here which is nothing but the summation of three areas; one is that this area plus this area plus this area and this three area is nothing but your A, so this three area is shown here now again if I see that this one the A complement union B complement that is that A outside B outside, if you take the union of this two area, then this three area will be added, so this area plus this area plus this area so this two relationships also holds good.

Now again I am just reading this De Morgan’s law, when in A set identity all the subsets are replaced by their complements, all the unions by their intersections, all the intersections by unions, the identity preserved. So, I am just making all the symbols just opposite in the sense that if I say that intersection is opposite to the union or the subsets are opposite to their complements, then if I just make this conversion, then this identity preserved, this will be more clear in the next slide, when I just see this relationship.

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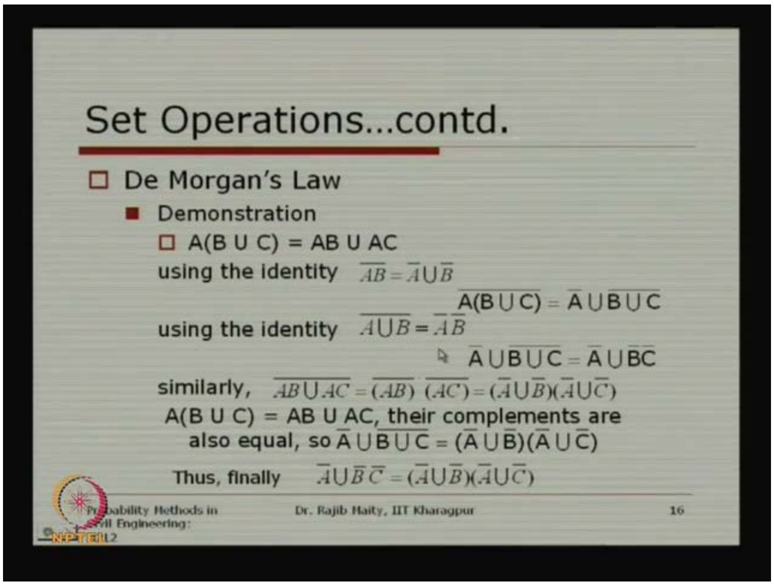

This is a demonstration of that what just now we told is that this is your A intersection B union C, and A A intersection B union A C; you can even draw another figure just to see that whether these two quantity are same or not; you can see by a simple Venn diagram that these two quantity are same. Now you see this relationship, and you just see the last line first before you go through all these steps, just see the last line here. Now this A here, this A is replaced by its complement, this intersection is replaced by the union, this B is replaced by its complement, this union is replaced by intersection, this C is replaced by this C complement.

Similarly on the right hand side, this A is replaced by it is A complement, intersection is replaced by union, B replaced by B complement similarly, this union replaced by this intersection A by A complement intersection by union and C by C C complement. So according to the De Morgan's law if this two are equal, then again this two this two also will be will also be equal.

Now, let us see that in between, how we can show this thing. Just in the previous slide we showed that this A B A intersection B complement is A complement union B complement. So using this one and we described this one with this simple Venn diagram, using this relationship here that A intersection B complement equals to A complement union B complement. If we use this identity and we want to put this one is that A intersection B union C full complement. So this is one set A, and this is B union C is another set, so this is a corresponds to A here and B union C corresponds to another set B here, then using this relationship we can write that this A complement union B union C complement. Again this in the previous slide another identity that A union B complement is equals to A complement intersection B complement; using this identity, we are we can even this B union C from this right hand side, we can just write that A complement union B union C using this one now, this B corresponds to A and C corresponds to B, we can write that A complement union B complement intersection C complement.

Similarly, so from this one I just prove that this is equals to this quantity; similarly, if I use that A intersection B union A intersection C and its complement, this will be equal to using this identity again; they are the A intersection B corresponds to A and A intersection C corresponds to B, then using this identity, I can explain that this is A intersection B its complement intersection A intersection C its complement, which is again equal to by using this back sorry using this identity; using this identity A B equals to A complement union B complement; we just put this one here, so that we will get A complement union B complement and A complement union C complement.

Now you see this relationship that is this one is equals to this, and this entity this set is equals to this entity. Now, I have started with the relation that this set, this full set is equals to this full set. Now, so if these two are equal, then their complements are also equal; now this is nothing but the complement of the left hand side, and this one is nothing but the complement of this one. So if this two are equal then this two are also equal, so I can write that this entity is equals to this entity. So that way what I can write is that I am just writing this one here and this entity here. So I am finally, getting this statement, which if I compare with the first statement, then all the sets are replaced by their complements all the intersections replaced by their union, all the unions replaced by their intersection and still we see that if we do all this replacement, then still the identity is result; this is what is the De Morgan's law.

There is base using this De Morgan's law, we can we can utilize this De Morgan's law for another concept further to further take this concept, which is known as the duality concept; and that duality concept is written here.

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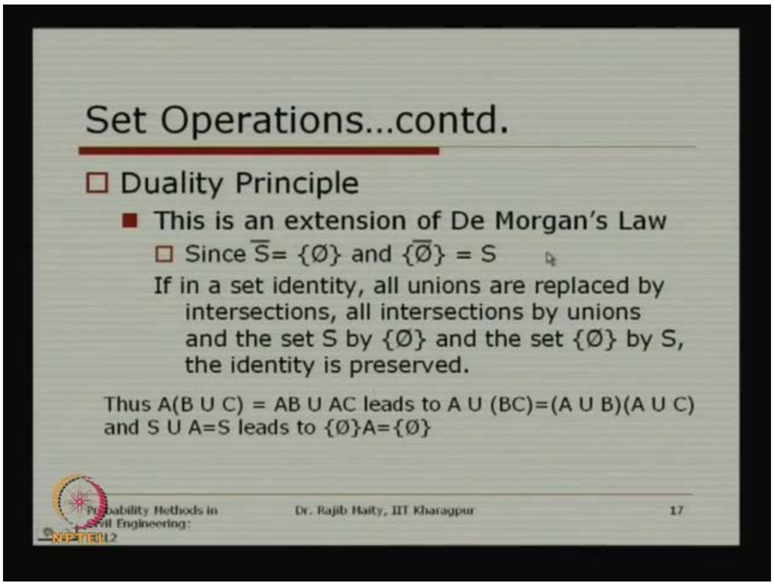

It is a, this is an simple extension of the De Morgan's law; here, this is the S is the full set, so if I say that S is the full set, then if I take its complement, which is nothing but a null set. So S consists of everything, so if I take that its complement, obviously its complement will be a null set and vice versa if I take the complement of a null set, then I will get back the full set, which known as S. Now if in a set identity, all the unions are replaced by intersection, all the intersections by their unions, the set S by the null set and the set and the null set by its set, then the full set S, the identity is preserved.

So, using this A intersection B, which is equals to this A B just in the previous slide we have just shown the this one, then this will lead to I will just simply changing this intersection as union and union as intersection on both ends both side left hand side and right hand side, then we get the another side another identity which is also preserved.

Then S union A is equals to S obviously the full set if I take the union of any sub set of this S, then that is also leads to this S, which leads to if I just replace this whatever I told here the S by the null set union by the intersection and A by this one, then it will written as this S is null set; so you see that the null set intersection A is the null set. So this is known as the duality principle, which is an extension of the De Morgan’s law.

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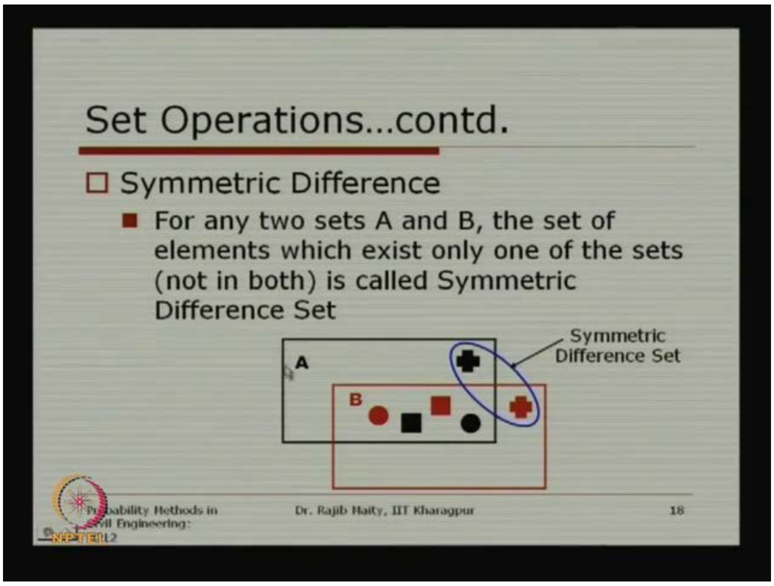

There are few other concepts also which are also useful in the set operation say for example, that first one is the symmetric difference; the symmetric difference for any two sets A and B, the set of elements which exist only one of the set not in both called the symmetric set. Here you can see there are two sets; one is one this one is the black rectangle which is denoted as a and another set is denoted by B which is a A rectangle; here there are few elements, which are common both in A and B in this area that you can see and which are not in not common, which are located in this area or in this area. Now if I prepare another set, which consists of all the elements, which falls either in a either in only A and or only in B, then the set that is the symmetric difference between this A and B.

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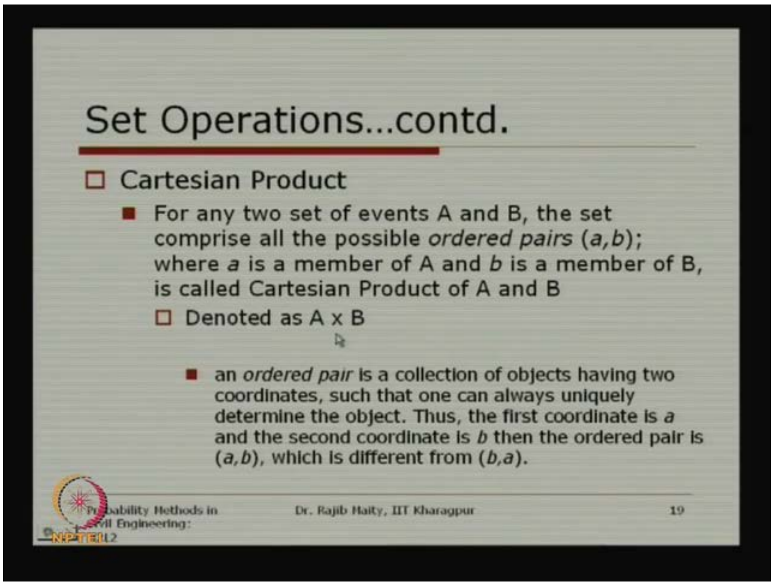

The second one is the cartesian product; for any two sets of events A and B, the set comprise of all possible ordered pair this is a new term will just explain it in a moment; the all possible ordered pair A B, where A is a member of A and the small B is a member of B, B set, then this all the possible ordered pair is called the cartesian product of A and B, and which is denoted as a cross B. Now, what is this ordered pair? An ordered pair is a collection of objects having two coordinates, such that one can always uniquely determine the object; thus the first coordinate is A and the second coordinate is B, then the ordered pair is A B. So always the first entity comes from the first set and the second entity comes from the second set, which is obviously different from the B A. So if we maintain the first entity of all the sets, all the elements, the first entity always comes from the first set and second entity always comes from the second set, then this is known as an ordered pair.

So once again the cartesian product if we see it states that for any two sets of events A and B, the set comprise all possible ordered pair A comma B, where A is a member of A and B is A member of B is called the cartesian product of A and B, which is denoted as A cross B.

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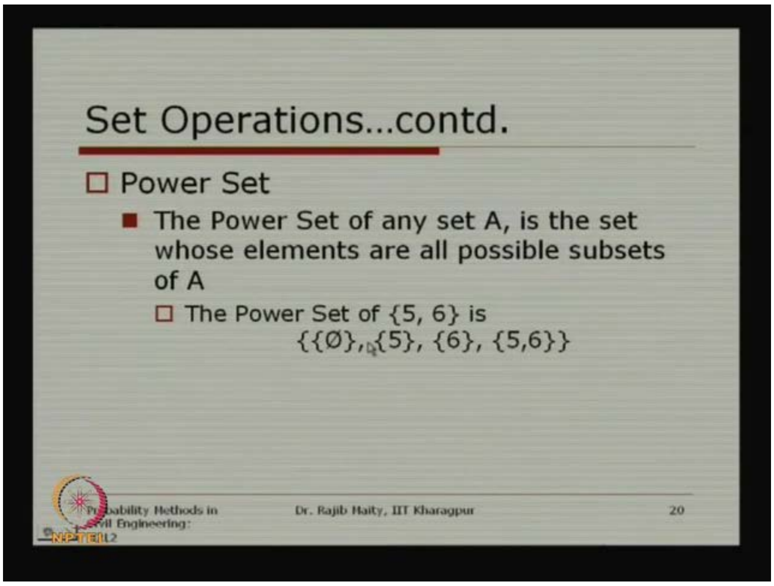

The third one is the power set the power set sometime this kind of terminologies are used frequently to have the concept is the power set of any particular set A is the set whose elements are all possible subsets of A. I repeat the power set of any particular set A is a set whose elements are all possible subsets of A. So if I just take one set that is 5 6, then the power set of this particular set can consist either the null set or the one element, the first element or the second element or another subset can be consists of the full set, the 5 6, so there are 4 possible subset that can happen. So this is known as the power set of this set 5 6. Generally, we say that this any particular set is one subset of its own power set, which is obviously true.

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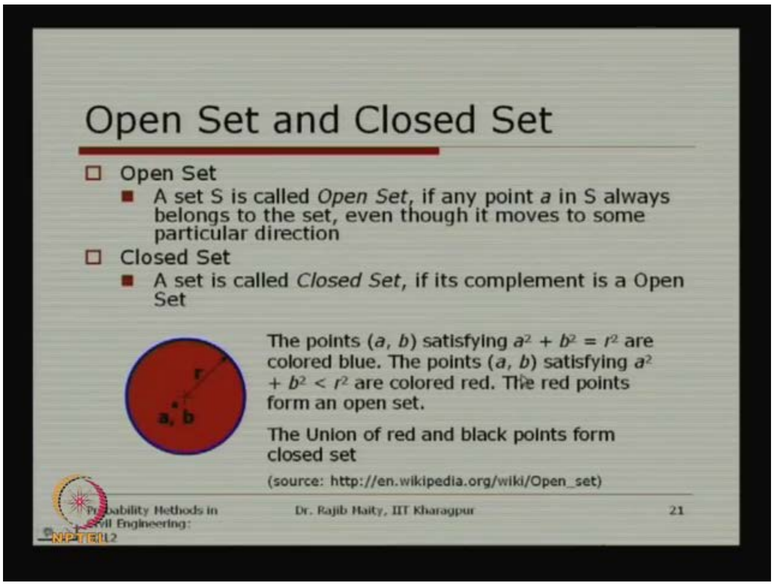

There are the there are two more thing that we say that open set and the closed set, the open set a set S is called open set, if any point A in S always belongs to the set even though it moves to some particular direction; and the closed set, a set is called the closed set if its complement is an open set. So the concept of open set is more important more important and the closed set we generally say that its complement, if its complement, if the complement of a set is open set, then that particular set is closed set. Before I go to this example if simply we say that a particular set that consists of all the integer numbers between 5 to 10, then this is a a closed set, and if I say its complement then it consists of the count ably infinite number a infinite numbers and that is obviously an open set.

A coming back to this particular example, which is taken from the Wikipedia the point a b if they satisfy this relationship that is a square plus b square equals to r square which nothing but an equation of one circle and which is shown by this blue line here this circle. Then a square plus b square is exactly equal to r square is color blue here though the points a b satisfying the a square plus b square less than equal to r square, these are colored red. So, there are this red area consists of many points, which satisfies the relationship a square plus b square less than less than r square, and this circle, this blue circle also consists of many points, where it which satisfies this relationship a square plus b square is equal to r square. This red points forms an open set this red points, what we can see that in between the inside this blue circle that forms an open set. The union of this red and the sorry this will be blue, the red and the blue points forms a closed set. The union of red and blue points forms the closed set, because if I take the complement of this union so this union is nothing but this full area red area including this blue area if I take the complement of this set, then it is completely outside so that is so that is an that is an open set; so that is why this union is a is a closed set.

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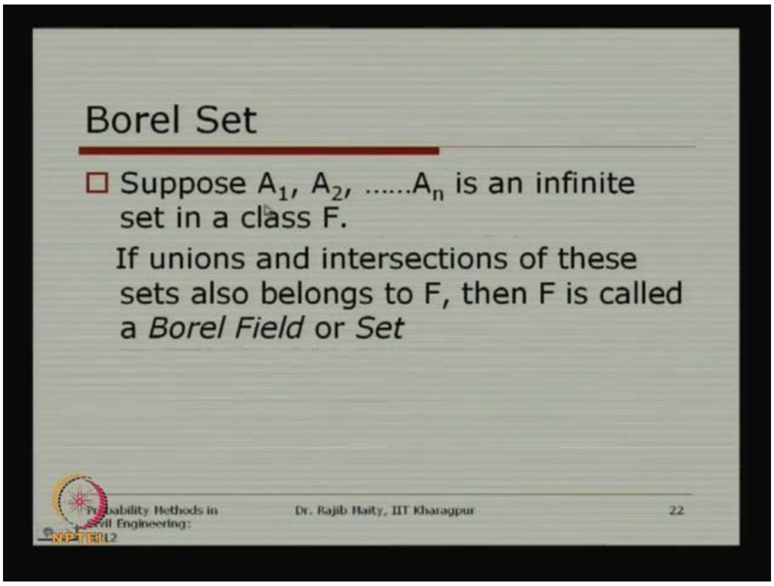

There is another important concept that is generally say that this is a this is a borel set, the concept like this, suppose there are some events n number of sets A 1, A 2 is an infinite sets, in some class F. Now, if you say that the union of union of any number of sets here from this A 1 to A n or intersection between any two or more than two sets, all this possible cases, all the unions all the intersection of this sets also belongs to same class F, then the F is known as the borel field or borel set. So this is important, when we say that we in particularly in the probability theory, when we say that there are some events, and which belongs to A class F whether that probability can be applied to their unions to their intersection, so to apply that one this condition must be satisfied that is that particular that particular set should be a a borel set borel set or a borel field.

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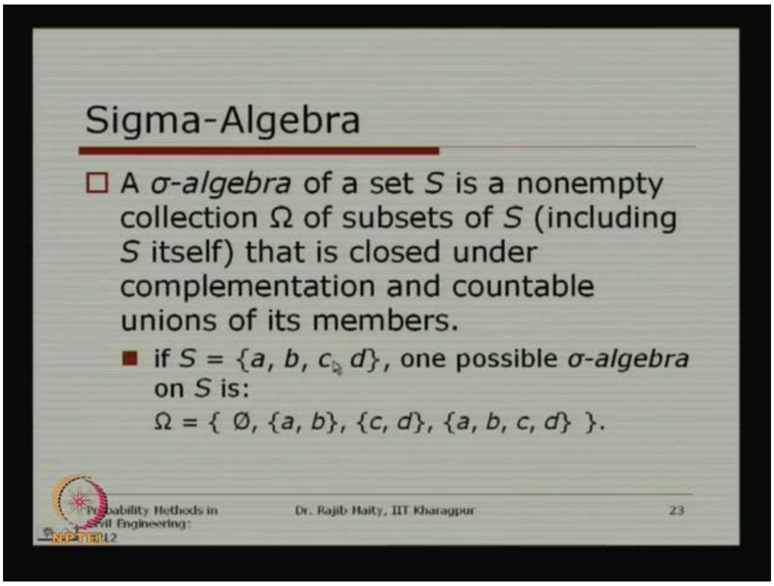

Another important thing is a sigma algebra, a sigma algebra is a set S is a non empty collection of non empty collection capital sigma here of sub sets of S, including S itself of obviously, S is also included that is closed under complementation and countable unions of its members. So there importantly there are three conditions; one is that that set must be non empty this is the first condition, second condition it should be closed set under its complementation. If I take its complements, then complements should also be closed; and the and the countable union of the set also is it is closed under this countable unions also. So there are three condition for a set if this three condition are satisfied, then that set is known as the sigma algebra. So, suppose here that this S consist of a, b, c, d is one possible sigma algebra on S is that this particular set the null set first two second two and these full set. So this is a possible sigma algebra on the a square this your that that collection of the particular set, this is a sigma algebra.

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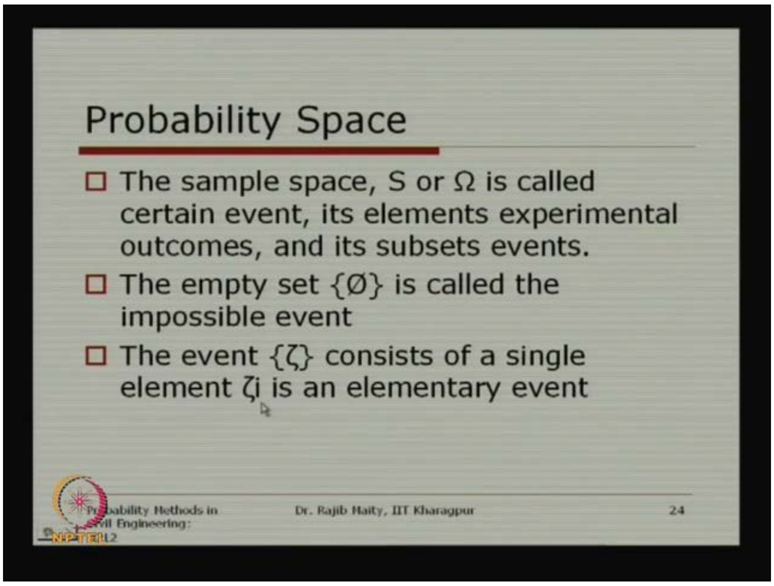

The probability space, this probability space here is important, because that this is the way how we link between the set theory and the probability concept. So in this probability concept the sample space S or sigma is called the certain event; it is elements experimental outcome and it is subsets are events. The empty set null set is called the impossible event, and the event joy concept of a single element is an elementary event. So, (( )) have samples space or this the or its sigma algebra is certain event in from the set theory the full sample space is consist of the certain event, its elements of the experimental outcomes; so in the whatever the experimental outcome the that we have taught in the in the previous classes; so its elements the elements of the set is the experimental out come and its subsets are correspond to some events. The empty set again here if I say some set is empty that means that is an impossible event, so for that experimental outcome that particular outcome is not possible is not possible; and obviously if it consist of a single elements single outcome that is an elementary event.

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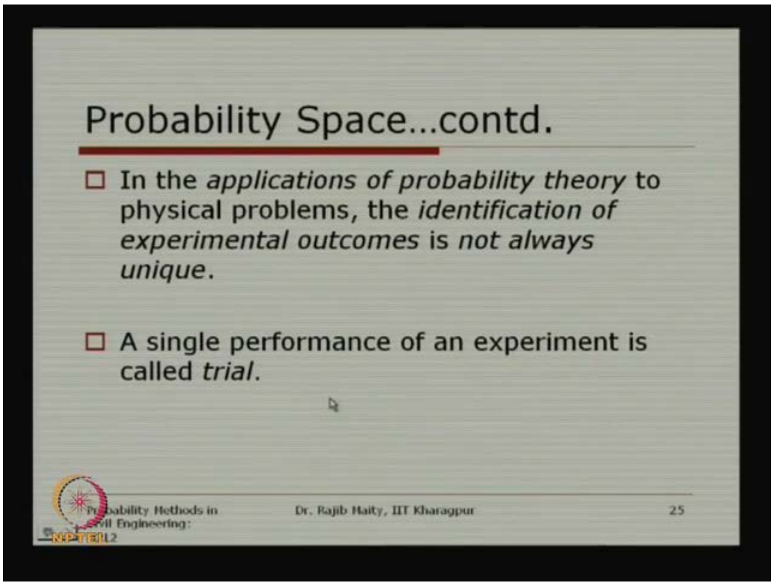

In the application of the probability theory to the physical problem, the its identification of the experimental outcome is not always unique. This is important in the sense that is how you are interpreting the a particular outcome of an event that that generally consist of a in consist of how you are representing that particular outcome for example, if I say that I am just interested to know whether the outcome of a throwing a dies is even number or odd number, then my possible sets or possible outcomes are two either it is even number or it is odd number, but if you say that it is if I say that the whether the outcome is 2, 4 or 6 we I am also looking for the even number but my possible outcome here that 2, 4 and 6, so there are three possible outcome in this in this representation.

Again if I say that if I through a die and its coordinate if I just fix up some coordinate system and say that the outcome is two and along with it is a location, where the two is comes. So, that location of die itself it is coordinate, its coordinate that is x coordinate and y coordinate on a plane obviously and the outcome is two. Then the number of possible outcome is infinite, so this is the way how a particular representation of a particular the application of this probability theory to a physical problems problem generally that this identifications of the outcome is not unique, the way we want to represent it is it becomes in that particular way.

A single performance of an experiment which we generally call is as a trail. So, a particular in particular trail whether a particular outcome will come that depends on this how the experiments is conducted, and that is the way we generally assign the that particular probability a single performance of an experiment is known as a particular trail.

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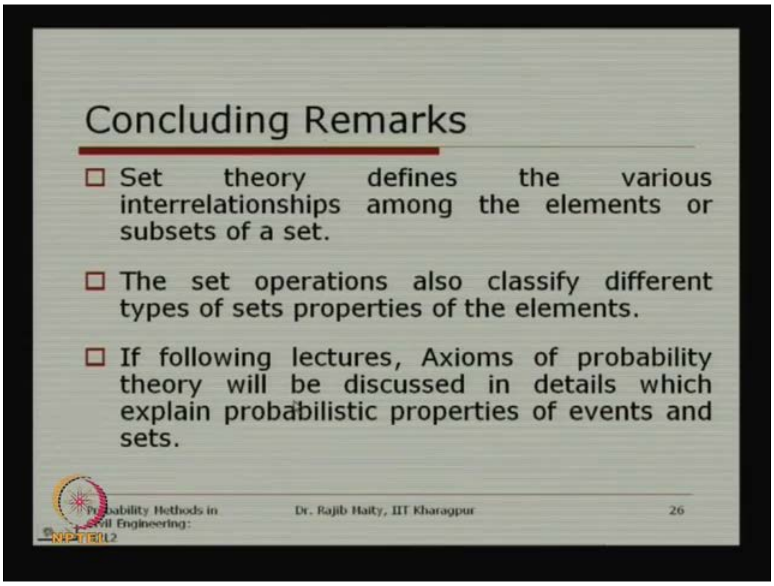

In the concluding remarks, in this class, we have seen that different set theory the definition of set and the set theory that defines the various inter relationship among the elements or the subset of subsets of a set. The set operations also classify the different types of sets, property of set properties of the elements. So, with this, in following lecture in the next lecture, we will a we will explain about the axioms of probability theory which will be discussed in the next class in details; that will very important for the probabilistic properties are events and set, thank you.