INDIAN INSTITUTE
OF
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KHARAGPUR

NPTEL
National Programme
on
Technology Enhanced Learning

Probability Methods in Civil Engineering

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Lecture – 04

Topic

Axioms of Probability

Hello there and welcome to the course Probability methods in Civil Engineering.

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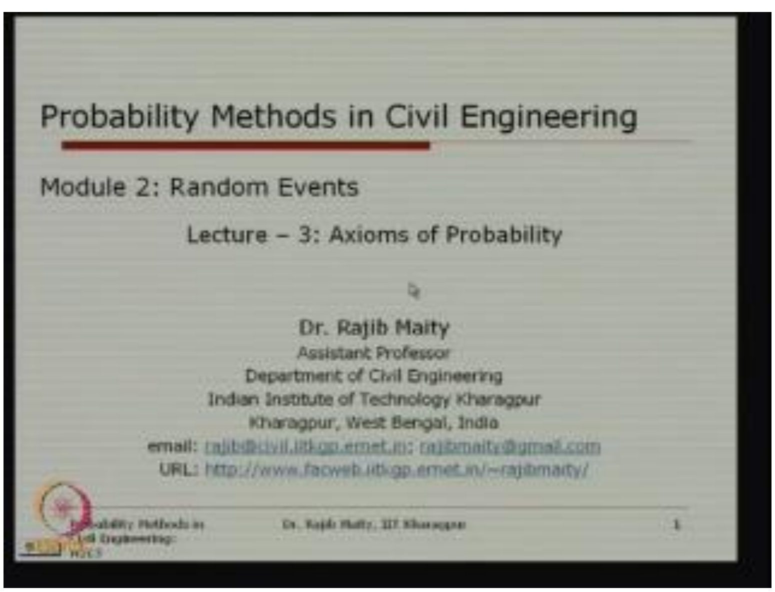

In today's class we are going through this module 2, which is Random Events and today is the third lecture in which we will cover the part called Axioms of Probability. So, these axioms basically are the fundamentals to the Probability theory and anything, any conclusion that we generally draw in the Theory of Probability, these are generally, directly or indirectly, somehow it is based on these axioms of probability. So, to know the Theory of Probability this one understanding these axioms are very important.

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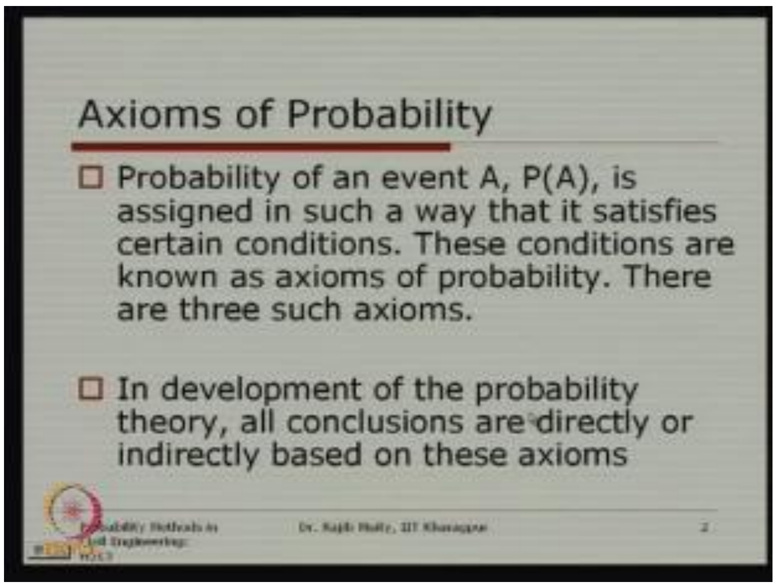

So, why is it important that we should first know the probability of an event A in the previous classes we have covered these concepts of event and sample space? So, here for to when we are going to assign probability to some event, we generally follow certain norms. So, here probability of an event A which is denoted as A is assigned in such a way that it satisfies certain conditions. These conditions are known as axioms of probability. There are three such axioms that will go one after another. In the development of this probability, as we just discussed is that in the development of this probability theory all conclusions are directly or indirectly based on these axioms.

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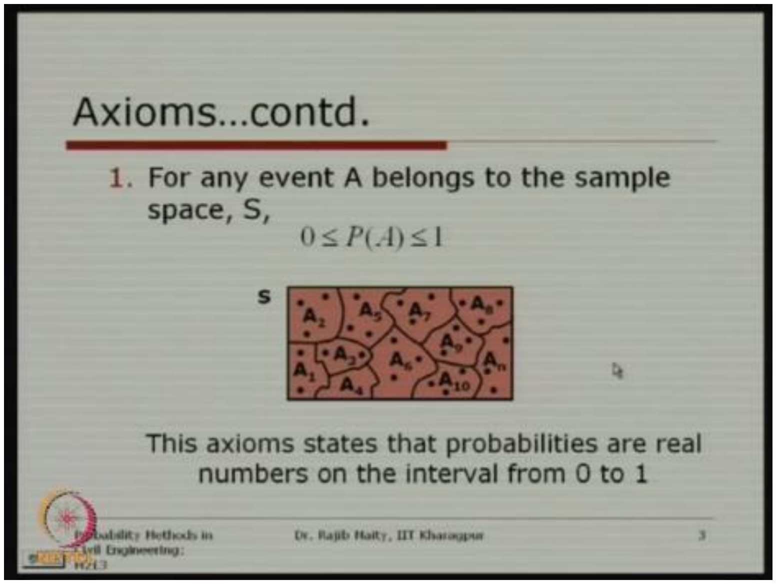

So, the first axiom says that, for any event A, which belongs to the sample space S as shown in this figure which is which should lie between the numbers real numbers 0 to1. So, it should be ≥ 0 and it should be ≤ 1.So, this axiom states that, the probability are real numbers on the interval from 0 to 1. Obviously here one point should be should automatically be known, that if a particular event that have no point if the event is a null set, then obviously the probability of that event equals to 1.

On the other hand if the event consists of the full set which is nothing but the axiom two and here we will go for this.

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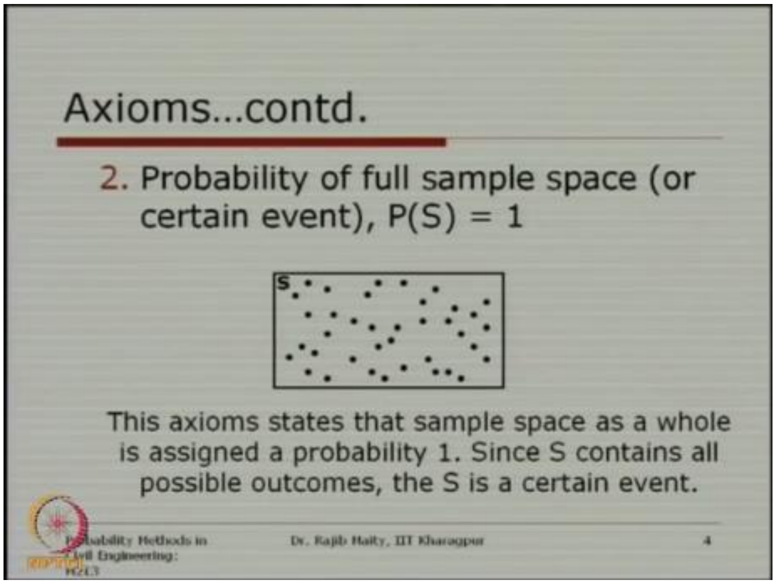

Axiom two is that the probability of the full sample space or the certain event which is denoted as S in the sample space the probability of S equals to 1.So if it if the event consists of all the sample space that means any one of this event if this event is a certain event. So, that is why the total probability which is probability of the full sample space which is equals to 1.This axiom states that the sample space as a whole is assigned sorry for the spelling mistake this will be axiom this axiom states that sample space as a whole is assigned to a probability 1. Since S contains all the possible outcomes the S is a certain event. So, this is the second axiom of this, of the probabilities.

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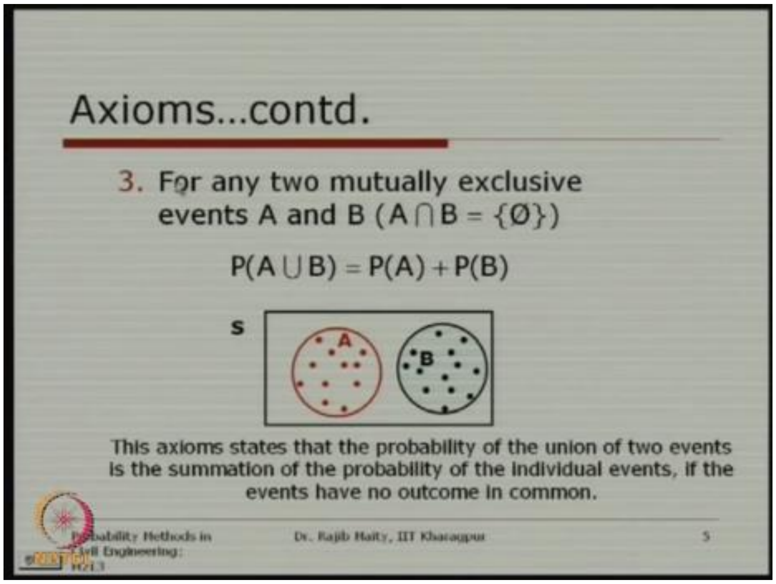

The third axiom states that for any two mutually exclusive, event now in the last class we discussed about this mutually exclusive event. The two mutually exclusive events means the two event if they are there is nothing in common so, then the occurrence of one event automatically implies the non-occurrence of the other event then these two events are known as mutually exclusive event. So, this axiom three states that, for any two mutually exclusive events A and B, that is A ∩ B is a {Ø} then probability of A U B is the summation of their individual probabilities.

That is P(A) + P(B) so, this axiom states that the probability of the union of two events is the summation of the probability of the individual event if the events have no outcome in common. So, if the events have no outcome in common that means that there is no space there is no overlap between these two events as it is shown in through this Venn diagram. That is the intersection between two events, is a {Ø}.

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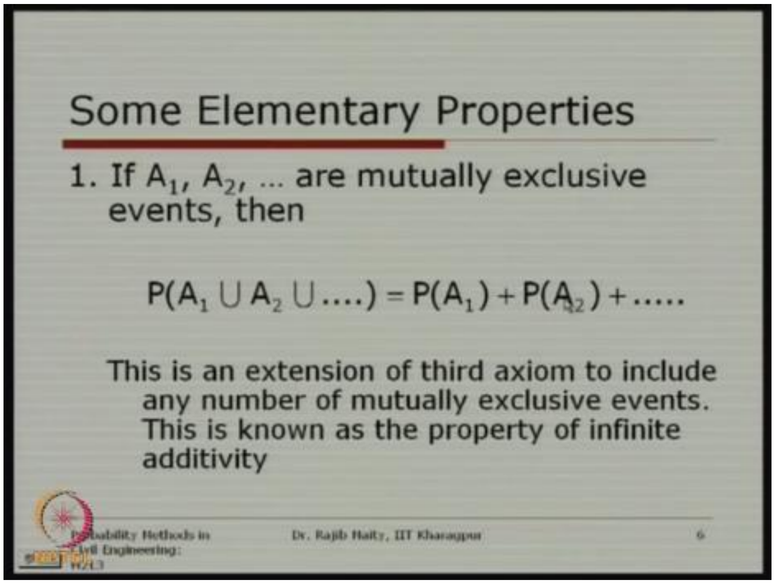

Now, based on this three axioms there are few elementary properties are there those are very useful to draw a certain conclusion from the from these axioms that we will go one after another. The first elementary property that we can draw from this one is just the extension of the last axiom that we have seen if A_1, A_2 and in this way these are mutually exclusive events then following the third axioms that is probability of the union of these events is simply the summation of the probability of all such events. So, this is basically an extension of the third axiom to include any number of mutually exclusive events.

This is known as the property of infinite additivity. So, for a sample space if we see if we can have the different events then and if we say that these events are not overlapping to each other than if we want to know what is the total probability of occurring any of these events then that can be achieved that can be obtained by a simply summing up the probabilities of the individuals events of summation of those probabilities for the individual events.

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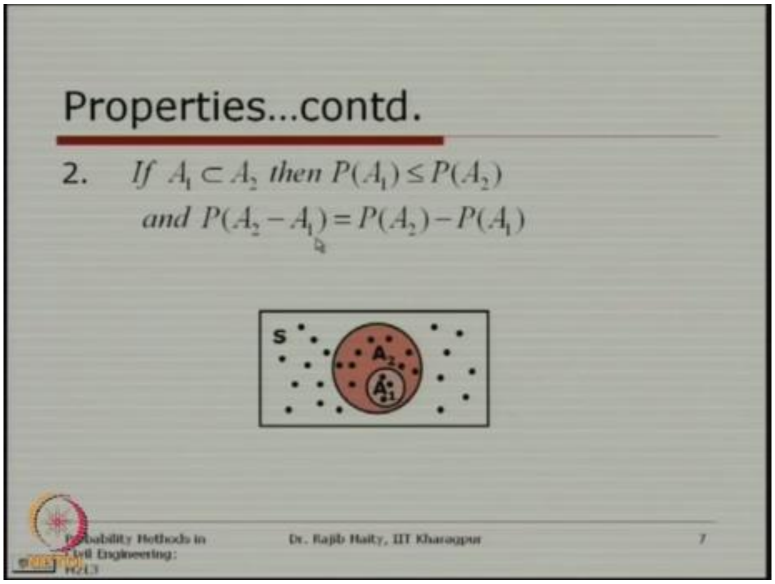

Second elementary property says if A_1 is one event which is belongs to A_2, that means if we refer to this particular Venn diagram, you see that if this A_1 is a subset of this bigger set A_2, which is denoted here as that $A_1 \in A_2$, then the $P(A_1) \le P(A_2)$ and $P(A_2)$ –$P(A_1)$ it is equal to $P(A_2)$ sorry, $P(A_2)$ - $P(A_1)$ so in this Venn diagram to represent this one this $P(A_2)$ - $P(A_1)$ is nothing but this dark red area which is nothing but this $P(A_2)$ is the total is the total probability as shown in this inside the bigger circle minus the probability of this small subset of this A_2, which is quite straight forward, from this Venn diagram representation.

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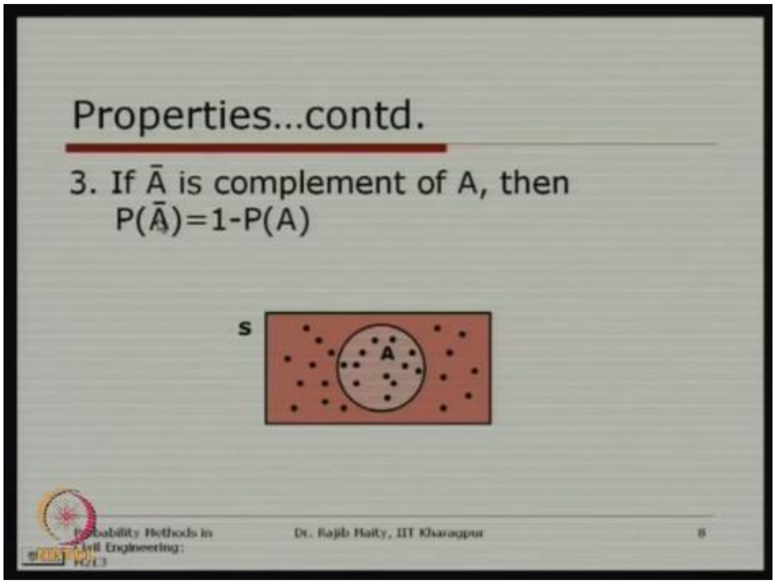

The third property is, if that A complement, that is A bar, is the complement of the event A, then the probability of A complement is equals to 1 - P(A). Here one thing is that the that event A and its complement union of this two events consist of the full set. Now, if you see here if this is your

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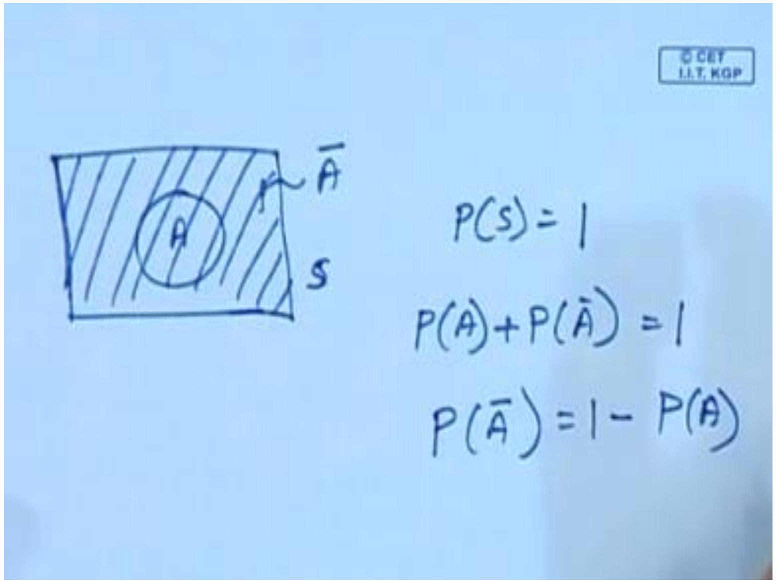

If this is your full sample space then and if this is your event A then the event A and the event this area is your event A complement. That means the union of these two event is nothing but the full set which is the which is full sample space S. Now from the second axiom we know that the P(S). is equals to one. So, what we can so this S we can break by P(A) + P(A^c) so, that we will get this equals to 1. So, this P(A^c) is equals to 1-P(A). So from this second axiom, we got this particular conclusion which is shown here that P(A^c) is equals to the total probability which is 1 - P(A).

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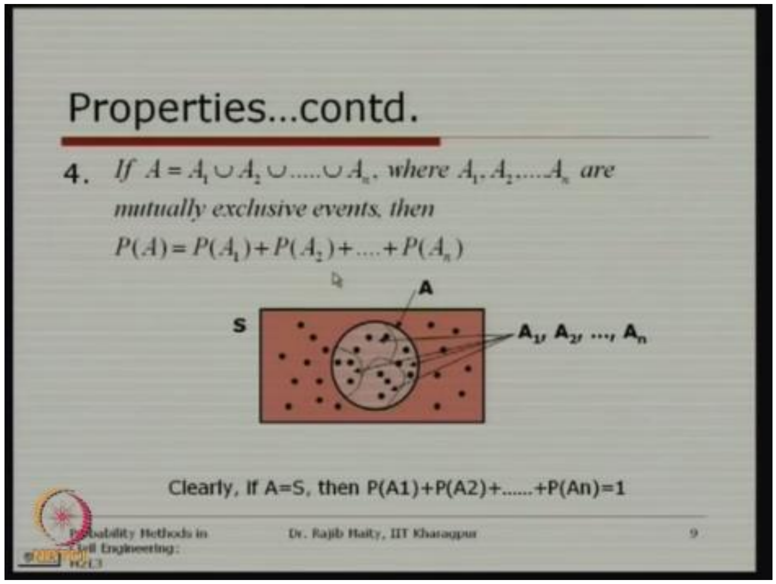

Then, the next property says that if we say it is just in the sense it is just opposite to the last property. Here if we say that one event which is the union of different n numbers of mutually exclusive events as it is written here if A U A1 to A_n or A_1 to A_n are the mutual exclusive event, then the probability of the total event that is A is nothing, but the summation of $P(A_1, A_2)$ up to $P(A_n)$ which is again the extension of those, that we just discuss that third axiom that in the third axiom.

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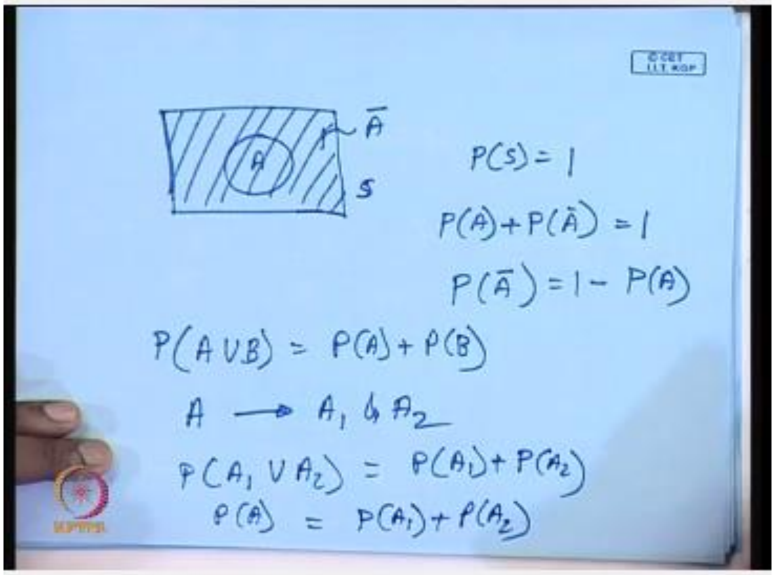

That probability of A∪B is equals to your P(A) + P(B) that means now if I say that P(A) + P(B) now in other side we are just saying that A is the split up of say for example, A 1 and A2 which are mutually exclusively of course, then P(A1 ∪ A2) = P(A1) + P(A2) And this A1 ∪ A2 is nothing, but p(A) = P(A1) + P(A2). Now just by going on this induction if I just say that.

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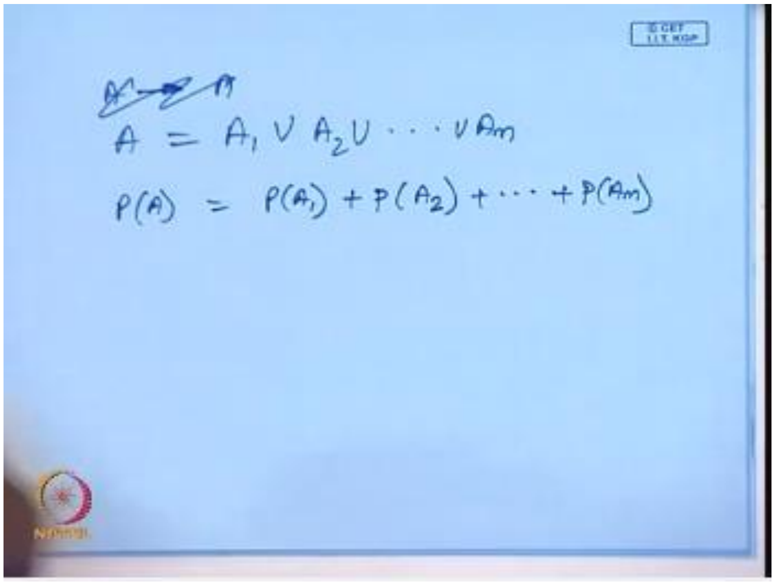

This A is the A is the union of so A also I can write that A equals to the union of this events up to An then obviously the P(A) = P(A1) + P(A2) and in this way it will go up to P(An) which is here I have shown in this diagram.

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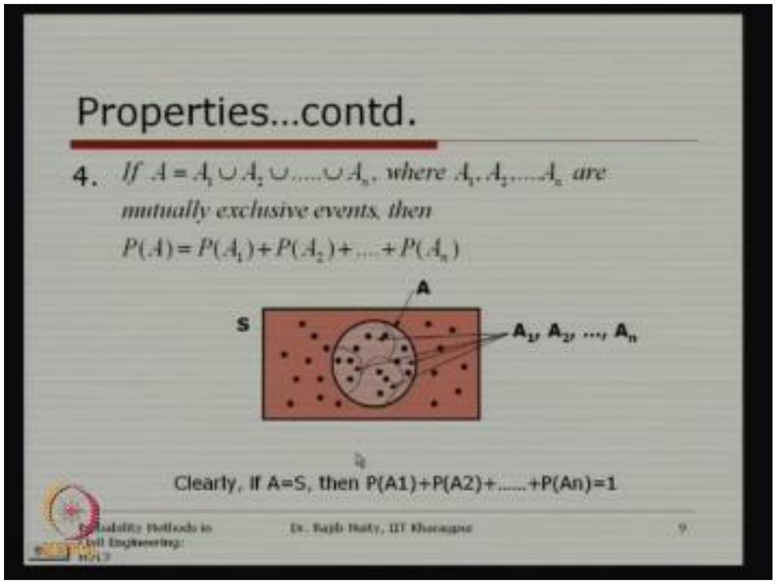

That if these are the partition partitioned in such a way that these are mutually exclusive events then the probability of A should be equals to the summation of their individual probability. So now if I replace this A so if so this is also going to this If I just replace this A in terms of this full set full sample space and this full sample space is partitioned like this and it is collectively if it is exhaustive,.

Then we can say that P(A1) + P(A2) ……P(An) = P(S) which is nothing but equals to 1.So if for if the full sample space is partitioned into A1, A2….An which are mutually exclusive and collectively exhaustive then the summation of these probabilities are equals to 1.Then so this one also we discussed one in the last lecture also.

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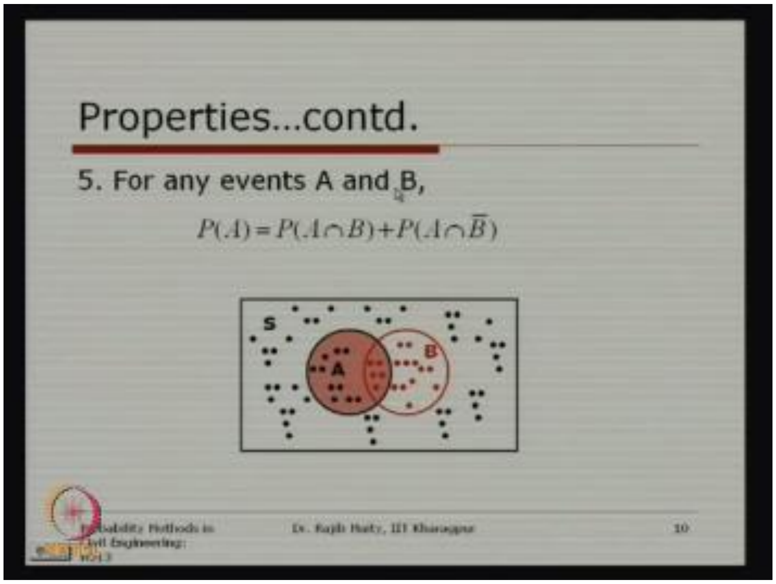

For any two events in the sample space this is the fifth property now, for any two events A and B inside this sample space which is shown in this Venn diagram one is that black shaded circle and one is the red circle these are two events. Now any one event any one event the probability of the one event can be expressed in terms of this expression.

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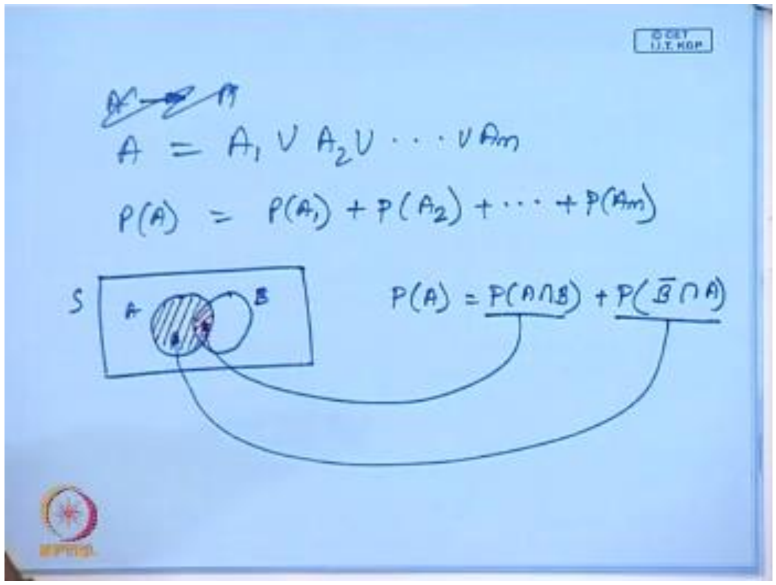

Now if we just see here that is this is your full sample space. Now we are having the two events A and B now if we want to know what is the probability of A this is equals to what we are doing is that this probability of A we are just making it the summation of two zones one is that this red set shaded zone and another one is this particular this black shaded zone. Now what is this that your red set shaded zone?

This red shaded zone is the P(A) ∩ P(A). So this much done, now what is this black shaded zone? This black shaded zone again is the intersection of two events one is that B, B' so outside this B area the full area is the B' ∩ A. So which is nothing but this black shaded area. So which is your B' ∩ A .So, these are the two events so this event corresponds to this red zone and this one this probability corresponds to this zone. So, this is these two summation is nothing but your probability of A. Here if you see that this probability.

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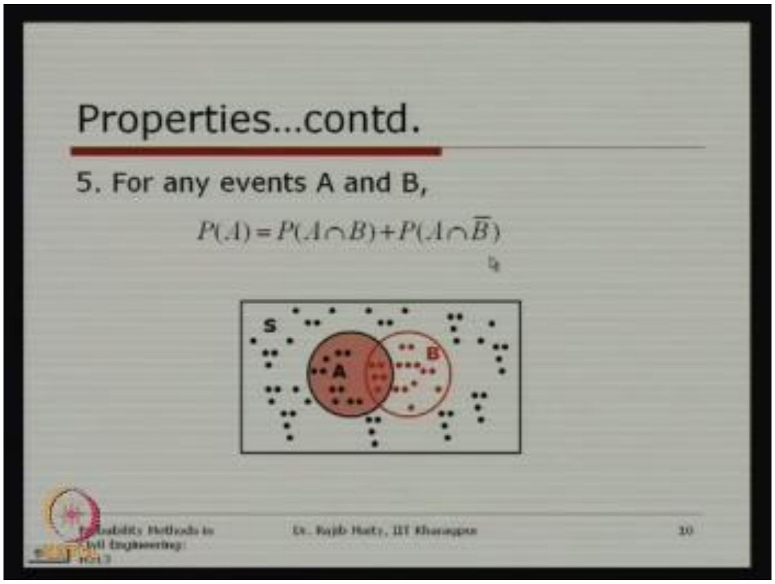

If you see the monitor here you see that this P(A) = P(A) ∩ B which is nothing but this zone and this A∩B' which is nothing but this area. So one particular the probability of any one event can be expressed in terms of the summation of its partition which is in terms of this two events in the sample space.

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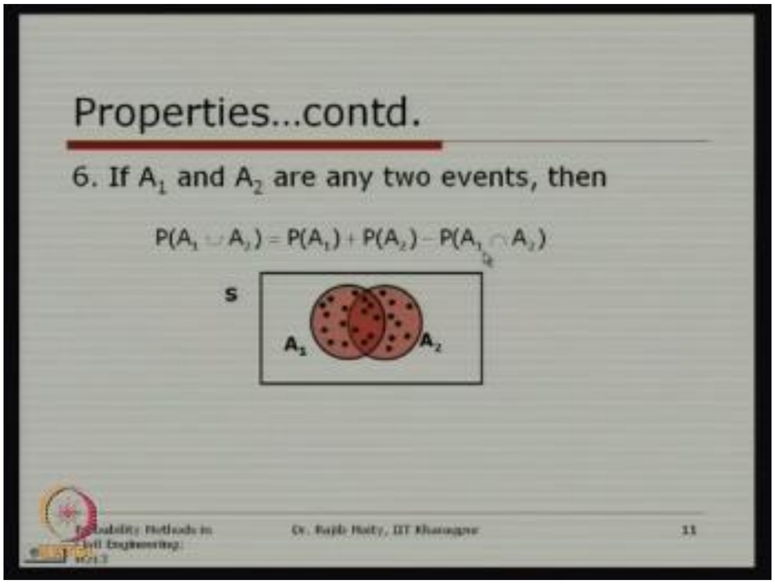

The next property tells us that if A1 and A2 are any two events then the P(A1 ∪ A 2) = P(A1) + P(A2) – P(A1∩A2) This is one or this important in the sense you see as you if you compare this property with respect to the third axiom of this of this probability then we see that here it is the any two events so we are not putting the constant of this mutually exclusive event here. So here this A1 and A2 need not be mutually need not be mutually exclusive. So, if these are any two events then this is the expression that holds.

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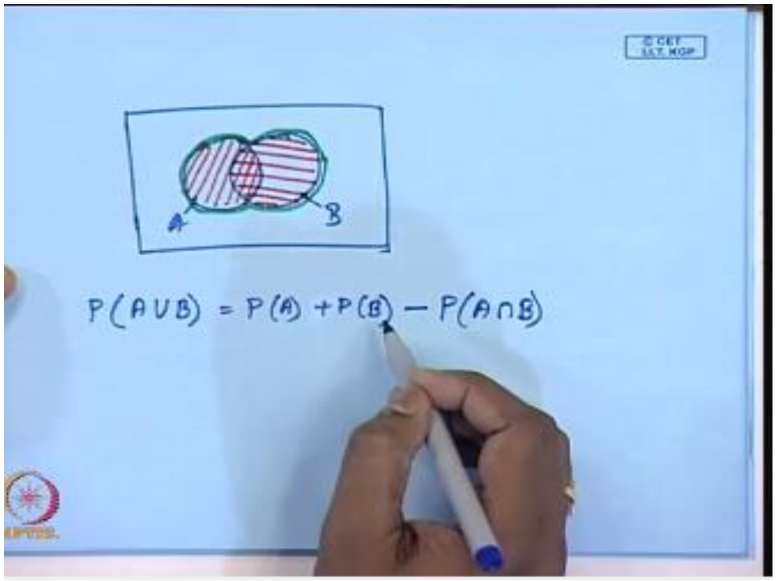

If you now see here that if in this area there are two events again what we are trying to get is that is the union if this is your A and if this is your B then what we are trying to get is the P(A) ∪ P(B). So, what is this P(A ∪ B) is this green area If I just draw it in the, along the side of this circles this union concept was given in the last class. So, this is your union of two events now this two events so how can I express this one?

First thing from this thing I can write P(A) that means I am just writing it I am just shading it the area corresponding area here in this Venn diagram which is this, this is your P(A). Now I am adding it up P(B) which is again I am just shading it in this, this is the area. So if you see while adding up this two process while adding up this two probabilities, we are adding this area twice, one which is there in P(A) and also in P(B).

That is why this area has to be has to be deducted. So, this is – P(A ∩ B). So, this is the graphical representation of this one this particular equation.

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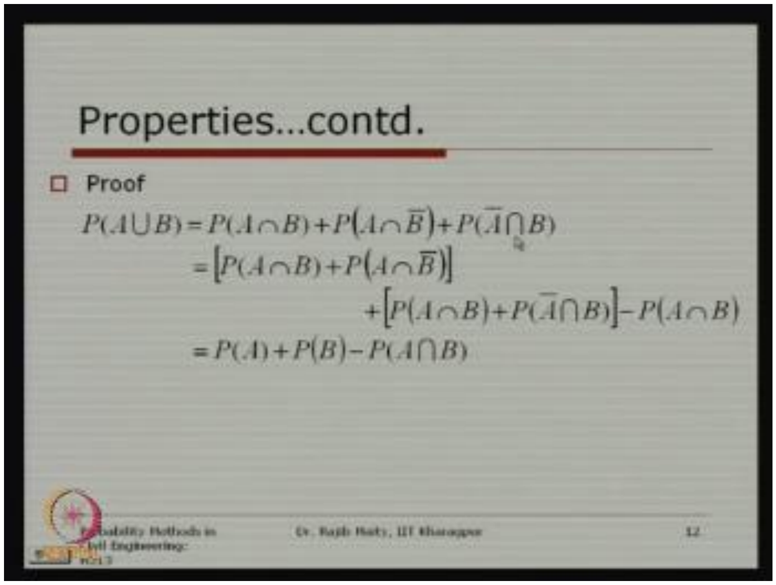

Now this equation can also be proven in terms of this what we have just now what you have seen the representation of one event in terms of in terms of the event, in terms of two different event in the sample space. So if we see that proof it states like these that P(A ∪ B) can be expressed in this way, that P(A∩B) plus this two. Now again, if you refer to this diagram.

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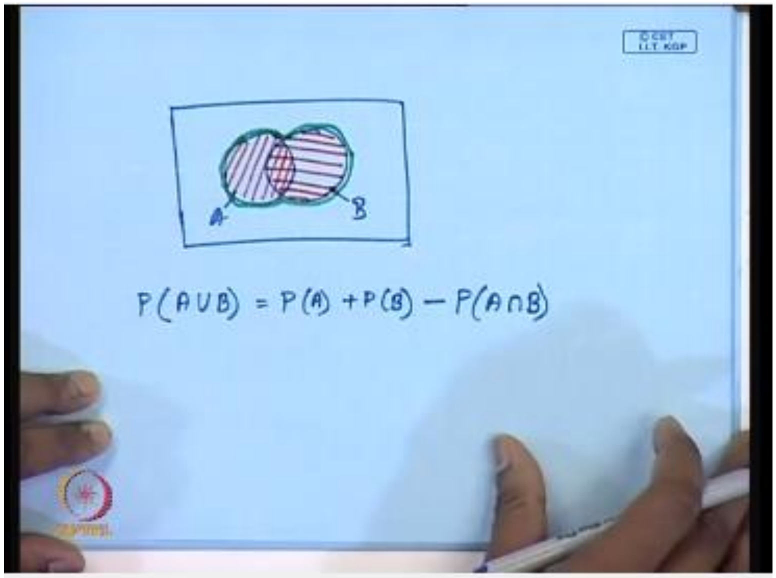

That this probability of I just take a separate sheet again.

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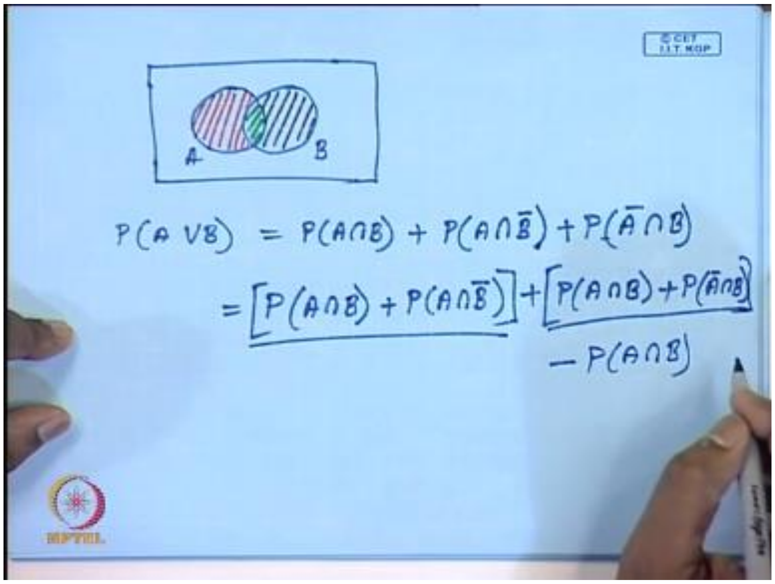

So now this one for this is A and this is your B. So P(A ∪ B) which is equals to I am just separating it out into three different places, one is the first one is this place, second one is your this area and third one is here, this particular thing. So then what we are getting is this middle one that is the intersection part P(A∩B) plus, so, this first area the way that we can write is that this is nothing.

But the intersection between the B' that is outside B and intersection with the event A. So, this will give you this red shaded area. So, which I can write as this P(A∩B') So this is one corresponds to this red shaded area plus similarly if I want to write this black shaded area which is P(A'∩B). Now these events can be now these events can be written that probability of A intersection B + probability of A intersection B prime I am just clubbing this two part together + I am adding one more part which is probability of A intersection B + I am taking this term which is probability of A complementary B intersection with B.

So I have added one part here so I have to delete this part to make this equality probability of A intersection B now this one if you just match and this one if you just match with our fifth property that we have seen.

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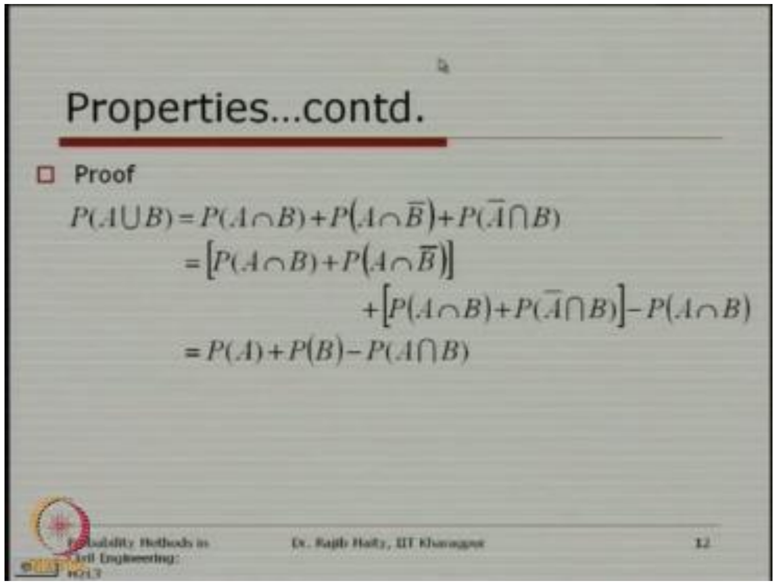

In the monitor if you see.

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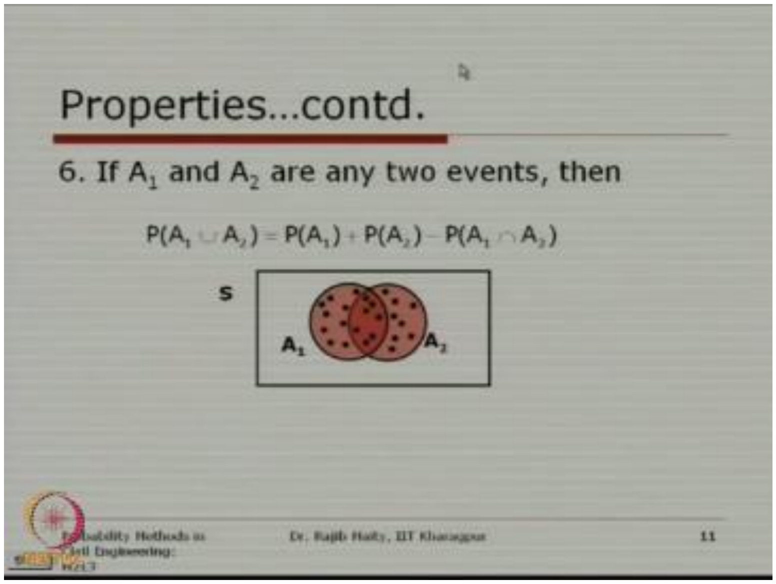

Just.

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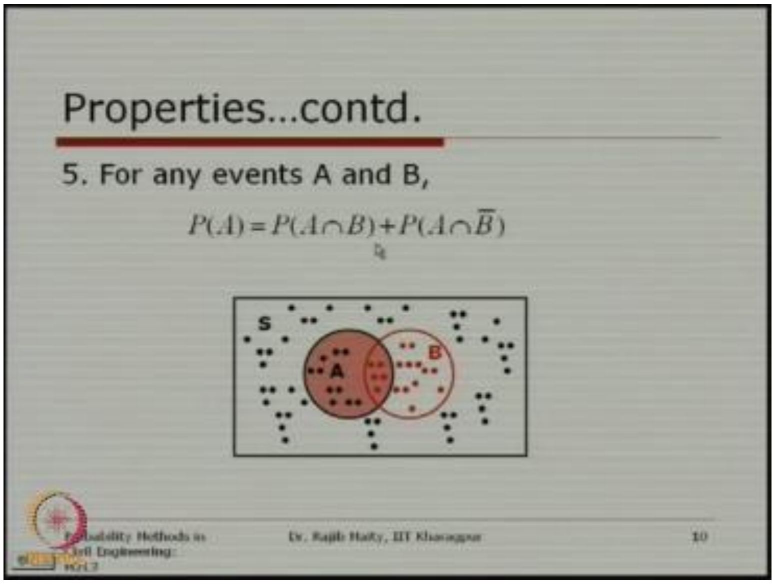

If you just see in this one then in the fifth of property then what we can do here.

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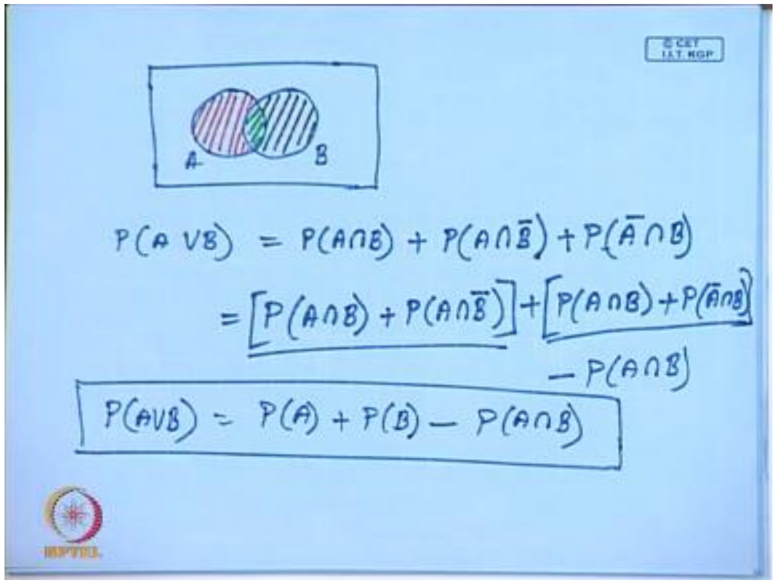

If you see it here so this we can write as probability of A and similarly this we can write as probability of B and obviously this minus probability of A ∩ B which is obviously this A U B.

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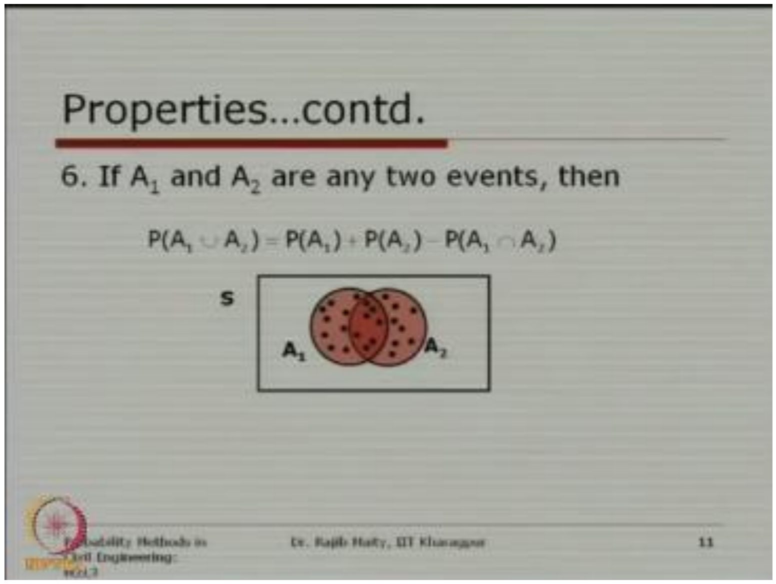

So this proof is given.

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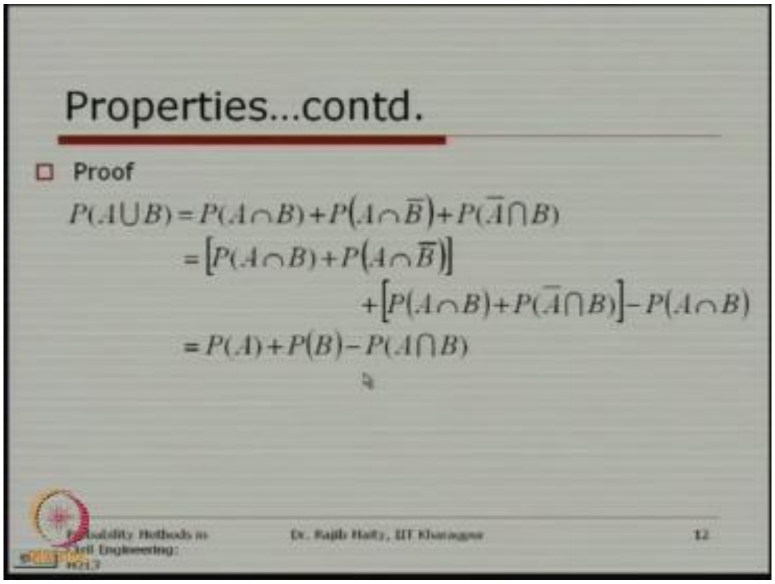

Here on this slide also these are the breakup of three this three probabilities which is shown in the Venn diagram there and there are some algebraic calculation to get this proof the next property rather I should say that this is the extension of instead of having this two events if we have more than two events if we have the three events then this will be simply the extension of this thing which can be easily.

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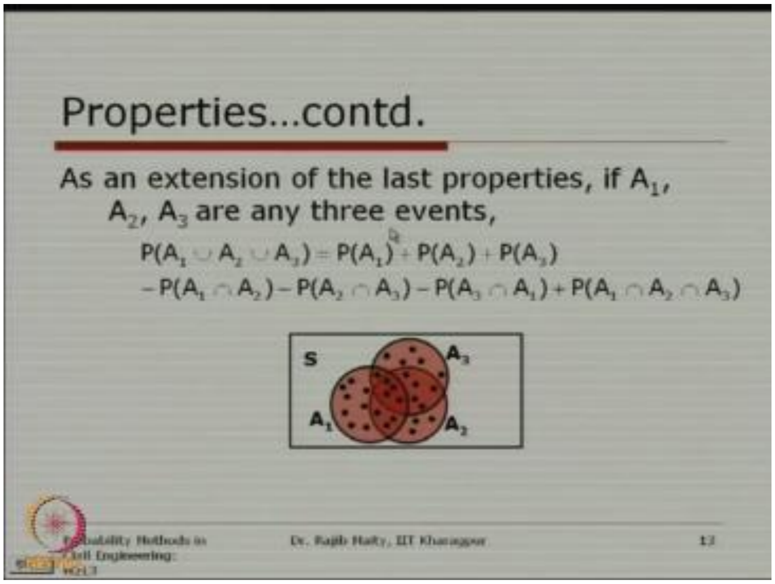

Shown in terms of this Venn diagram here what we are saying that that if these A 1, A 2 and A 3 are any three events in the sample space then what is the probability of A 1 U A 2 U A 3 so similarly what we should do we should add up these probability of A1, which corresponds to this circle here you can see probability of A 2 this one and probability of A 3 which is this now after doing all after adding all this probabilities what we are doing that we are adding individual intersection the pair-wise intersection of these probabilities twice.

So we have to deduct that part so we are deducting this first pair A 1, A 2 - A 2 A 3 - A 3 A now while doing this deduction from this one we can see that this particular area has been deducted once more so we have to add this particular area which is the intersection of all three events so have to add this part that is probability of A 1A 2 A 3 ∩ so this is just a simple extension of this earlier thing if we just see if we just take out this part and this part you will see that this part is has been whatever the extra that part has been deducted again.

When, when you are taking the third pair this is one negative area is coming here so that have to add here to get this two are equal so this is the extension of this last property which is discussed in terms of two events here it is in terms of any three events.

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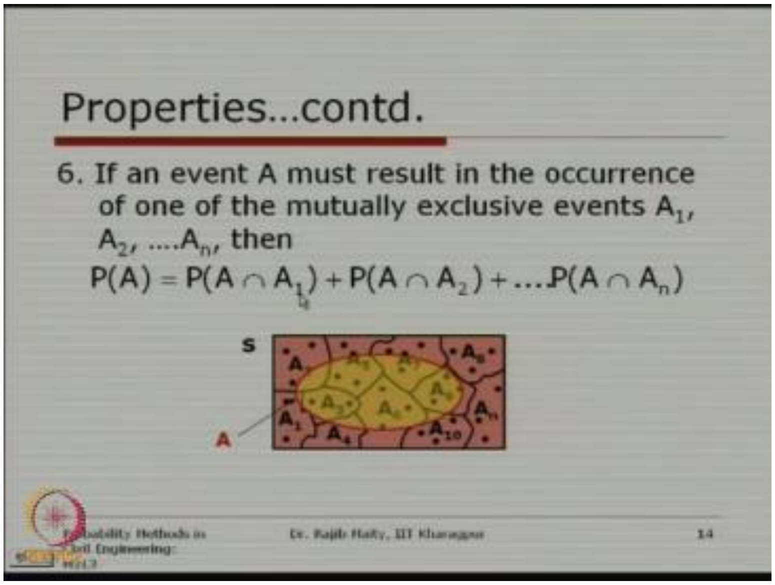

Now it is just a opposite sense of what we discuss in this fifth property this says that if an event A must result in the occurrence of one of the mutually exclusive event in A 1, A 2 and up to A_n then the probability of A can be expressed as their individual intersection if you just see it here in that.

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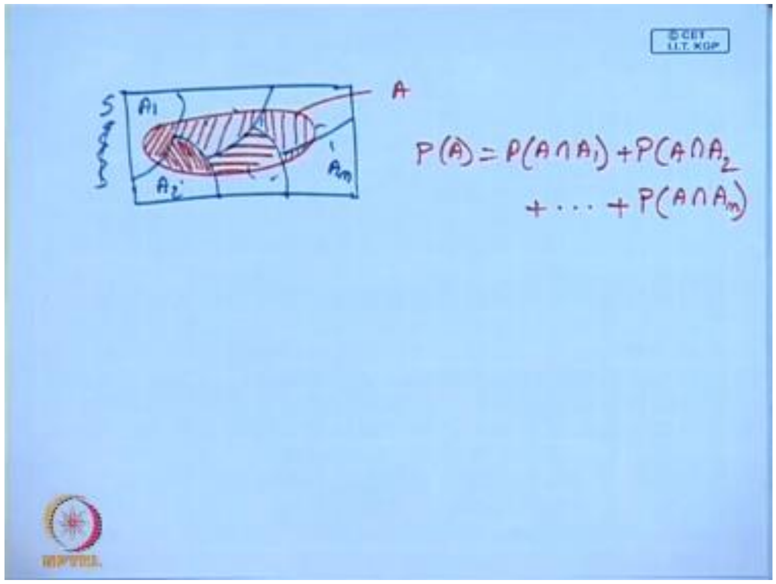

So if there is your sample space and this sample space is having the partition like that mutually exclusive and collectively exhaustive partitions are there and there is another event like this and if I say that these are all these partitions are this is total S this is partition is A 1, A 2 and up to this it is going and it is coming up to A_n and if I say that this event is your A, then this probability of A can be expressed as a summation of this particular area. First is this area so what is this area this area is nothing but the intersection between the event A and event A1.

So we just write it event A intersection event A1 + I am writing now this area this corresponding area in this Venn diagram which is nothing but probability of ∩ of A2 and this event A so A ∩A2 in this way I will go on adding up then this area will come and finally the last event will come so in this way I will just add up to probability of $A \cap A_n$. so this is stated.

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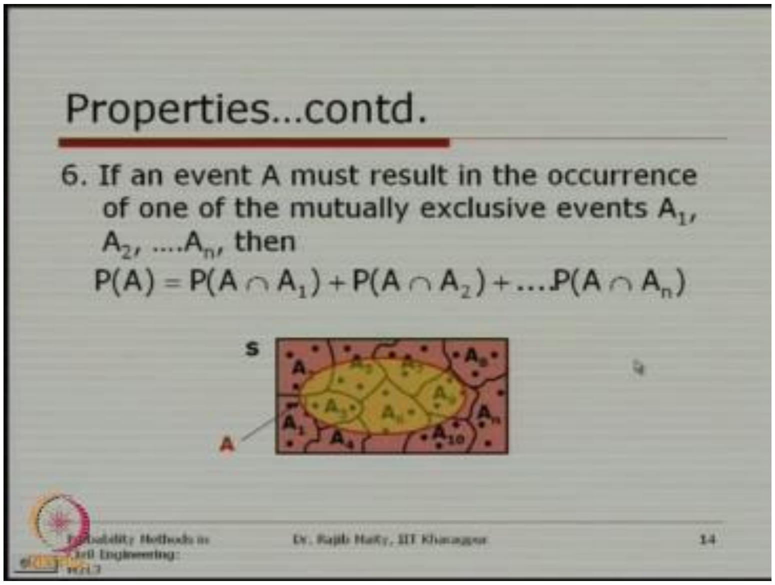

Here in this slide that if an event A must result in the occurrence of one of the mutually exclusive events A 1, A 2 up to A_n, then probability of A is a summation of the intersection of that event with the individual events A1up to A_n so the next property.

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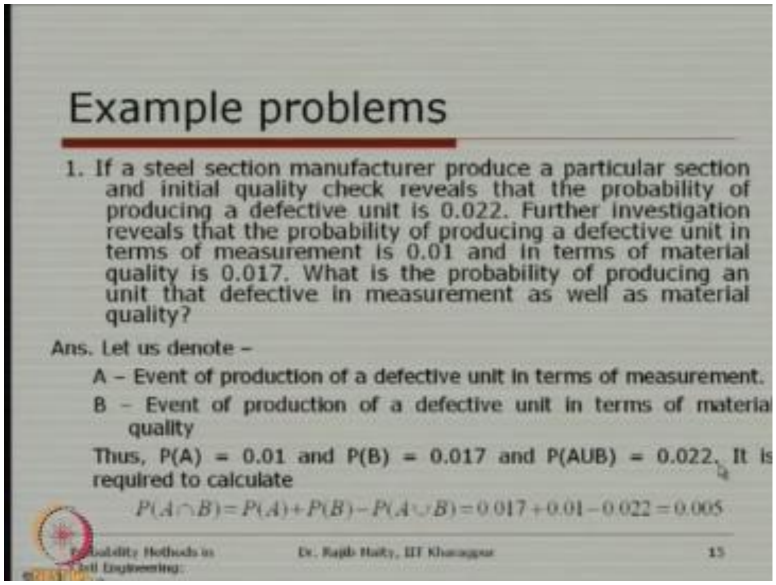

The before we go to that one that is on the on the conditional probability that we will see in a minute. Before that we will just see we will just quickly go through one small example problem which states like this that if a steel section manufacturer produce a particular section and the initial quality check reveals that the probability of producing a defective unit is 0.022 further investigation reveals that he probability of producing a defective unit in terms of the measurement is 0.01 and the defective unit in terms of the material quality is 0.017 then what is the probability of producing an unit.

That is defective in measurement as well as in material quality so here what the information is given is that what is the total probability of producing a defective unit is given and these two events that is probability of the it is defective it can be defective in two different ways one way of defective unit is that this measurement is the measurement was wrong and other one is that the material quality was not satisfied so in two different way the particular section can be defective so their individual probability that we got is 0.01 and another one the 0.017and the total is given here.

This 0.22 the question is that what is the probability of producing an unit which is defective in terms of both that is it is defective in terms of the measurement and also in the material quality so we here we can we can assign two different two different events the first event is that it says that it is event A that event says that the event of production of A of a defective unit in terms of the measurement so this is your first thing and the second is that B that is event of production of the defective unit in terms of the material quality.

So from the problem the information that is supplied is the what is the probability of A and what is the probability of B so probability of A is your 0.01 and probability B is 0.017 and it is also that supplied what is the probability A U B, that is the whatever way it is the defective unit probability of defective unit is 0.022 so here the idea is that this when we are saying.

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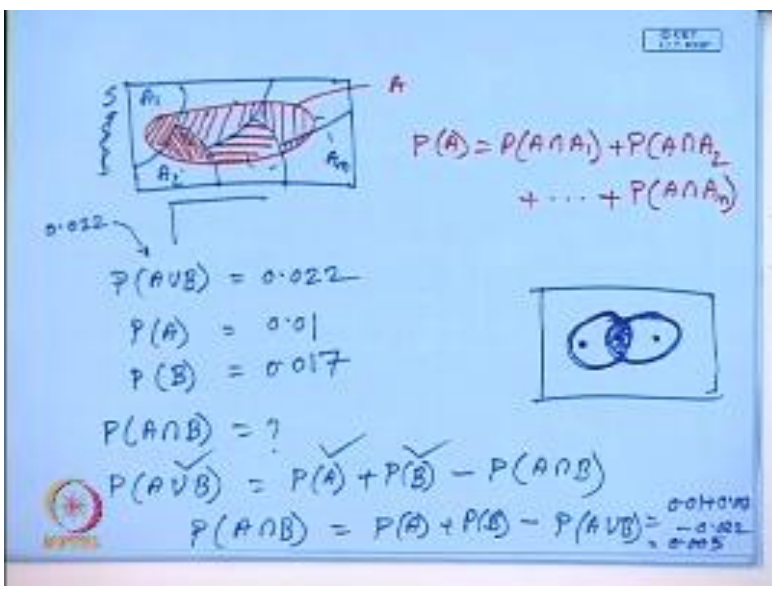

That probability of A U B that means if you if we again refer to that Venn diagram that A and this B so this A U B that is when and saying that the unit, a particular section is defective it can be anywhere. It can be either, it can be defective in case of only for the reason, only for the event A, it can be defective by both or it can be defective by the second event, that is event B.

So, that is why, whatever the, the defect, the probability of a defective unit that is the value is given 0.022. This should refer to this probability of AUB. So, there is the probability of AUB is given, so0.022. Also, we have seen that probability of individual event, that is the probability of A is given as 0.01and probability of B is given as 0.017.

So, now, it is asked that, what is the probability that a particular unit is defective in terms of both, that is in terms of its measurement as well as the material quality? Now, so, here according to this Venn diagram, we are basically referring in to this intersection, of this two, this two event, that is the, we are, we want to know what is the probability AnB. Now, we know, so, do this one thus, one simple property that we have use.

We should use this one, that is probability of AUB is equals to probability of A+ probability of B- probability of AnB. Now, this is known to, this is known and this is known. Obviously, this should be known, which is probability AnB equals to probability of A +probability of B- probability of AuB, which is 0.01, 0.017- 0.022 = 0.005. So, this, this refers to this particular area, where I can say that, this units is the defective, in terms of both measurement as well as your material, material quality.

This is simple application of that, that property that we discuss, that if there are two events which are, which are any two events, it does not, it does not mean that these two are mutually exclusive, and then we can use this property to get that simple answer.

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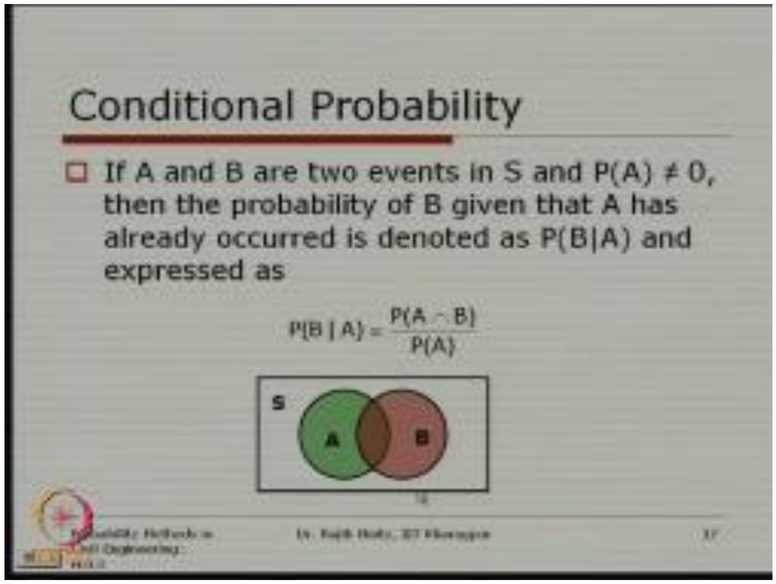

The next thing which is, which is, which we are going to cover is known as the, the conditional probability. Then this conditional probability means in the sample space what happens, these two events are given and you are interested to know the probability of a particular event giving some condition, that some, that other events has already occurred. Now, if these two events are shown here, as you can see in these Venn diagram, that is, this is the, this is the area that corresponds to these event A and these red is the corresponds to this B and this overlap between A and B is nothing but, the intersection of this two.

So, now, if you want to know, what the probability of B is, this can be obtained from this, that technique, that we discuss in the previous class. Obviously, we can also know what is the, what is the probability of the, of the individual event, probability of A as well as probability of B. Now, here, that, here the question that we are quoting is, the conditional, it is conditional means that I want to know the probability of one event, any one of these two event that, probability of A, probability of B, with certain condition. Here the condition is that, I am ensuring that occurrence of the other event, the occurrence of the other event here means that, here its means that, if that A and B are two events, are to be specific, any two events in the, in the sample space

S and the probability of A is not equal to 0, then the probability of B given that A has already occurred.

Now, the probability of B means, there is no condition is given here, which is, which we generally, which we simply write

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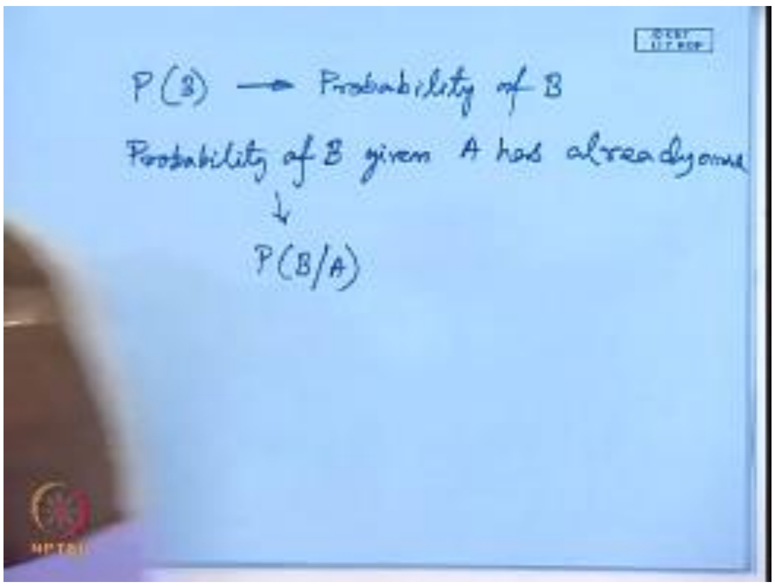

In terms of the probability of B. Now, what here, what we are seeing is that, this is your probability of B. Now, when we are saying that, when we are saying that, that probability, probability of B, that given A has already occurred. So, this we generally denote as probability of B given A. So, this is the notation for this one. So, the probability of B, given that A has occurred and this just simply the probability of B.

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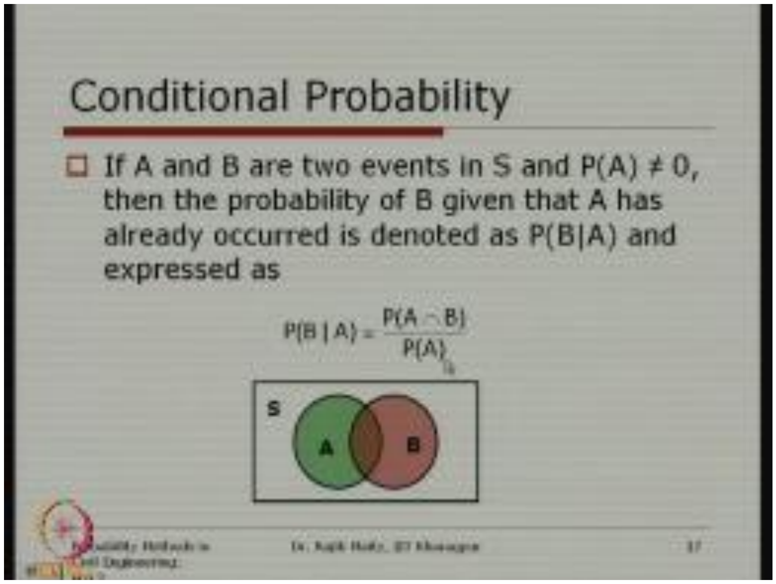

Now, if you come back to this one, then we see that, which is denoted as probability of B, given A and this is expressed as probability of B given A is equals to, this should be equals to, not 3, 1. Sorry for this mistake. So, this is equals to probability of A intersection B divided by probability of A.

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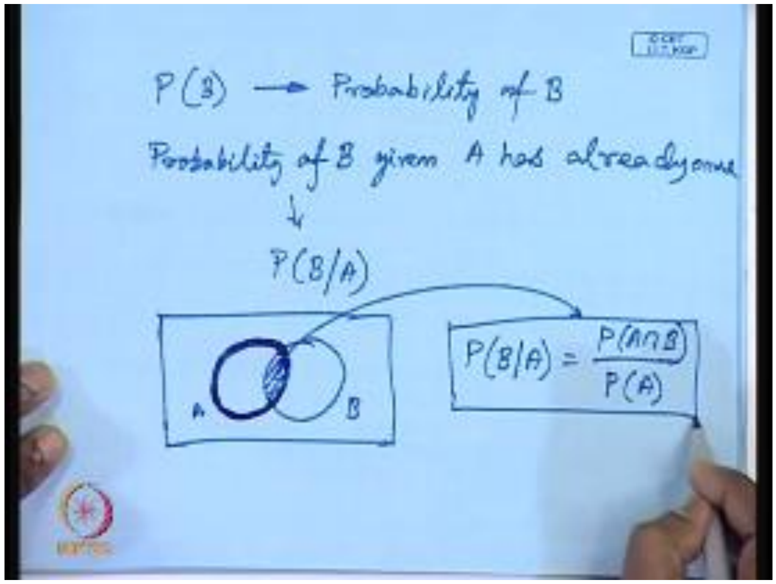

Now, if you just refer to this Venn diagram that is shown here, is that, this is your probability A and this is your probability B .Now, from the traditional definition, in this probability, we will just see, so, we are interested to know that, probability of B on condition A. Now, there must be something in the numerator and something in the denominator. So, in this denominator what you should get, it is the total possible case that you know from this, in the previous classes we discussed that, this denominator should have the total possible case. Now, here, what is the possible case?

The possible case is that, the, that given A has already occurred. So, now, if A has already occurred, so, I should ensure that, the whatever the outcome of the experiment, that outcome of this experiment is certainly within this A region, should corresponds to this particular area of this Venn diagram.

So, this is already in this one. When we are talking about this probability of B, the total feasible or total feasible space or the total sample space is the full sample space. Now, when we are giving some condition, the condition that A has already occurred, so, my, my feasible space is this total, this A. So, obviously in the denominator, this probability of A should occur and in the numerator you know that, we should, we should put the quantity which is the favorable case.

Now, we want to know what is the probability of B, condition that A has already occurred. A has already occurred, that is why I put in the denominator probability of A. Now, what is the probability of B? Now, the success area between, within this area, the success area is nothing but, this area. If it is in this area, then we can say that B has also, B has also occurred. So, what is this area corresponds to? This area is nothing but probability of AnB. So, this is your expression for this conditional probability, which says that probability of B given A has already occurred, which is equals to probability of AnB divided by probability of A.

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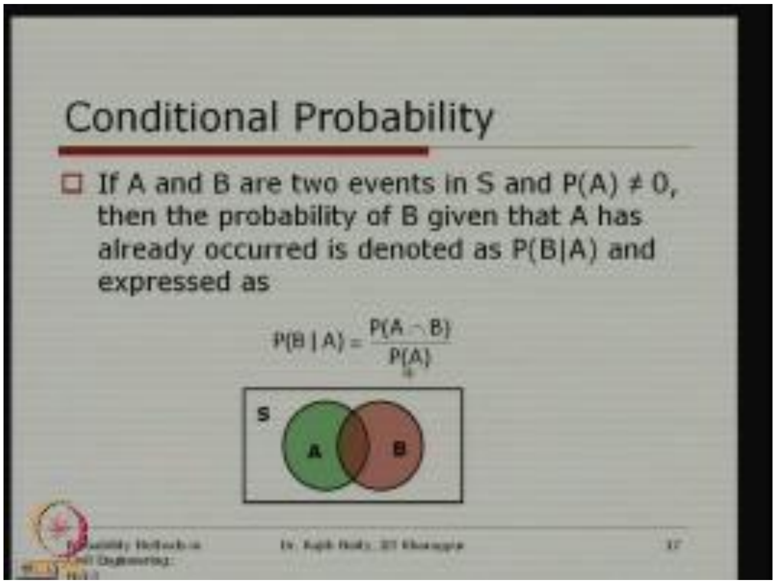

So, here, so, the something has been shown here, which is the probability of AnB is this shaded area, which is orange type area and probability of A means this green area plus this orange, and this area, this intersection area. So, this is the conditional probability. Now, we will see the application of this simple, this simple conditional probability equation.

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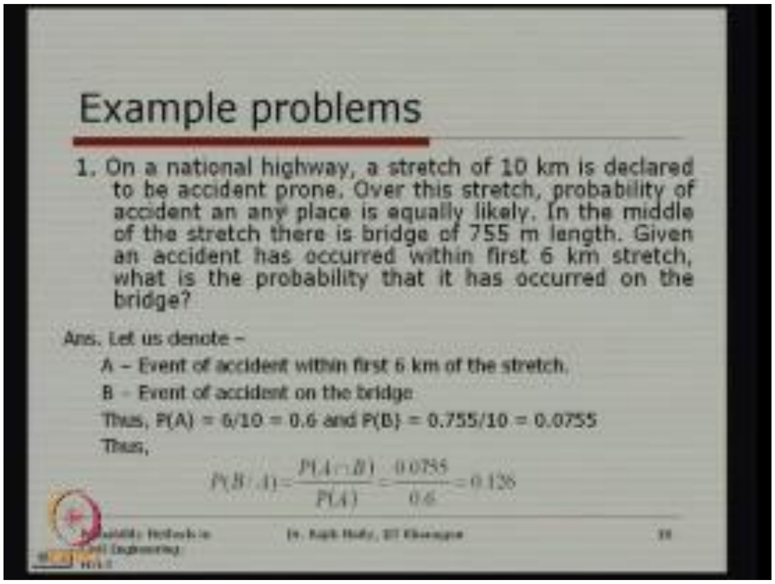

To some civil engineering related problem. Here, on a national highway, a stretch of10 kilo meter is declared to be the accident-prone zone. Now, over this stretch, the probability of accident, probability of accident at anyplace, sorry for this spelling mistake, at any place is equally likely. Now, here when, if you just recall, some of our previous class, here the equally likely means that I am just giving an ((attribute)), how to assign the probability for a particular events so, here the event means that one accident is taking place at any, over a any particular sub-stretch of this 10 kilo meter area and it is equally likely.

So, in the middle of this stretch, this 10 kilometers stretch there is a bridge of 755 meter length. Now, given, an accident has occurred within the first 6 kilo meter stretch, what is the probability that it has occurred on the bridge? Now, this is interesting, in the sense that.

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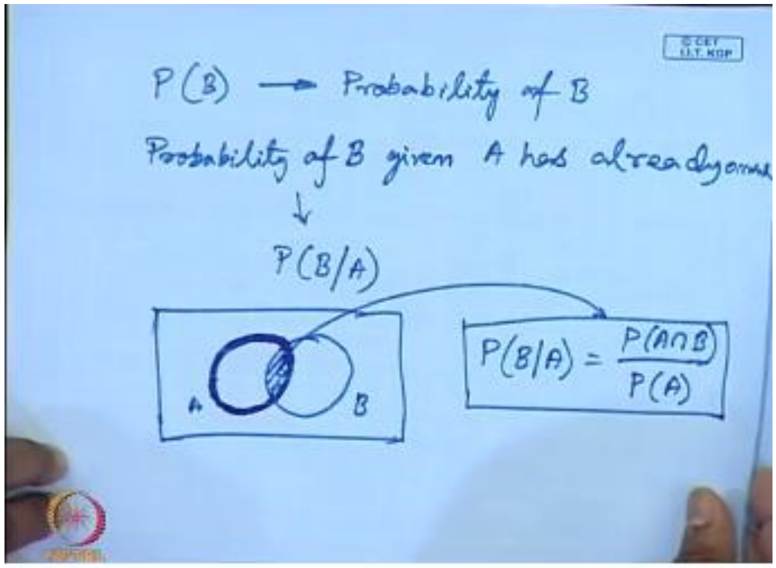

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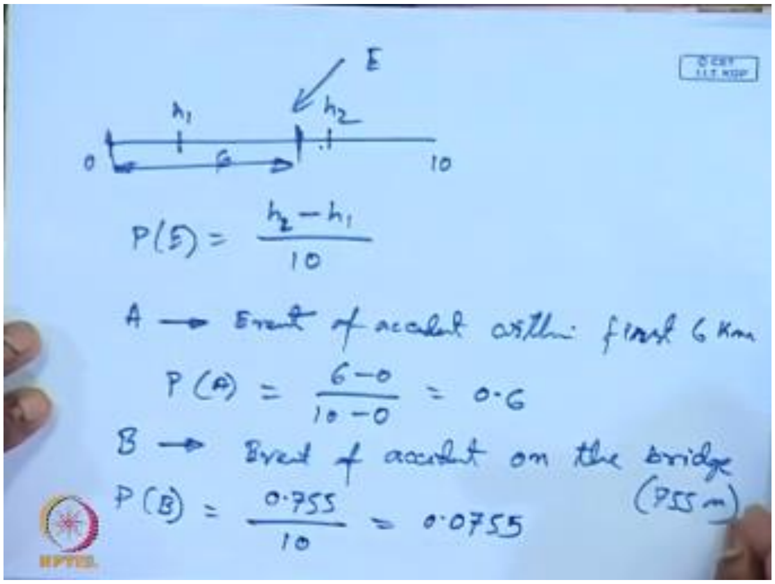

So, my total stretch is this, starting from 0 to10 kilometer. Now, I say that, this is equally likely accident prone area and it is equally likely. So, if given that any stretch, if I just give from 0 to or from the any kilometers range from h_1 to say h_2, the probability of the accident between this two range, the probability, if this is some event say E, then, probability of E should be equals to h_2 - h_1 / 10. So, this is this we can get from for the any event, that we can assign as, these are equally likely.

Now, for this problem, if we just assign that this is say A is one event that event of accident, within the first 6 kilometer, so, what is the, what is the probability of A that we will get here is nothing but so 6 minus 0 divided by 10 minus 0, which is 0.6. So from starting from here up to 6 kilo meter range the probability of the accident in between these two is your 0.6. Now if I assign if I just denote another event, the event of accident on the bridge.

Here the bridge is 755 meter length, so the probability of B will be it is equally likely all over the stretch. So this is also equally likely so this is 0.755. I am just converting them into kilometer which is 0.0755.

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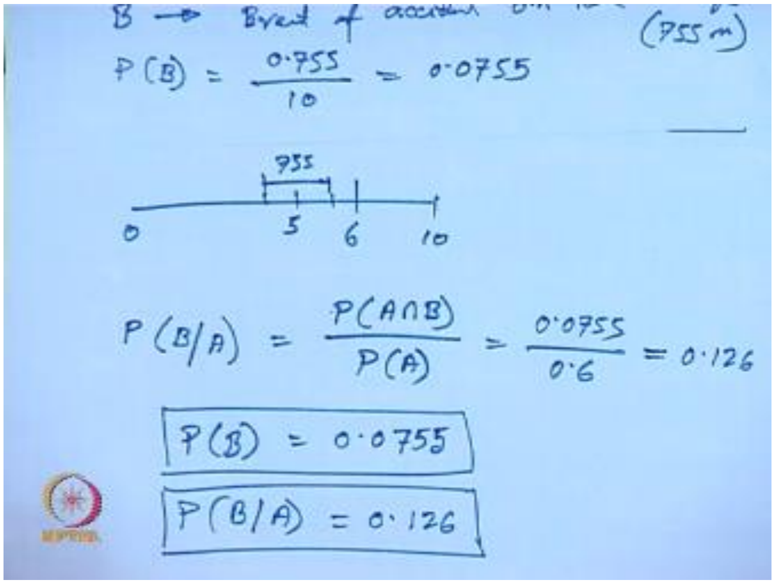

So our condition so here what is the probability that we want to know is that the probability of B that is it should occur on the bridge. What is the probability that it has occurred on the bridge that is the event B on condition, that it is occurred within the first 6 kilometer of the stretch? So this is B given A, just by putting it here. The probability of, then A intersection B, divided by probability of A.

Now, this probability of A intersection B can be so you have to see at the middle of this bridge so if this is the location on this bridge, then this is your 5 kilometer. So bridge has some length and this is within this first6 kilometer, most probably comes here. So this is your 755 meter, so the full bridge is coming within this first 6 kilometer range. So that means there is A intersection B is nothing but, so B is a subset of A.

So, the intersection obviously will be within this region. So which is nothing but, equal to the probability of B. So which is the probability of B, that you got earlier at that point 0.0755 divided by probability of A is 0.6, which is 0.126 as we got in this calculation. So, here if you just compare that, what is the probability of B is your 0.0755. So this is the probability that you got. Now when we are giving some condition the, that probability information changes, this is the useful thing that, we should know that if we give some condition, then the probability of the same event may change, as we have seen in this particular problem as well.

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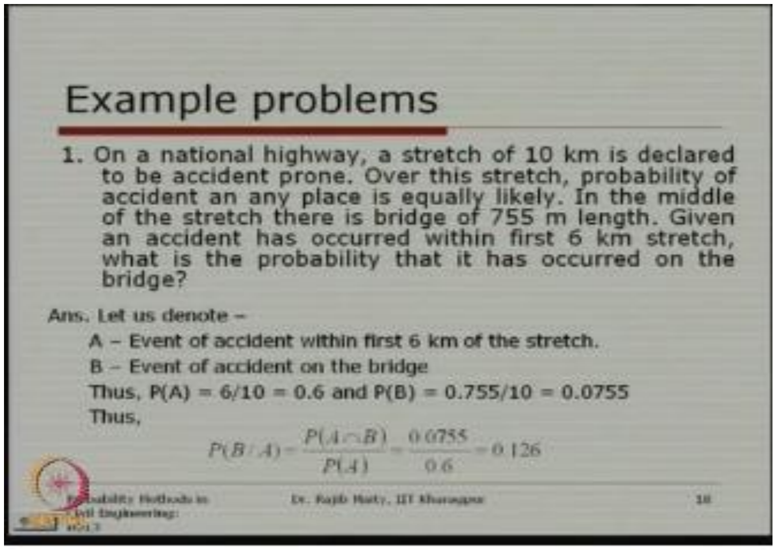

So here you can see that, this probability of B given that A, it comes to the 0.126.

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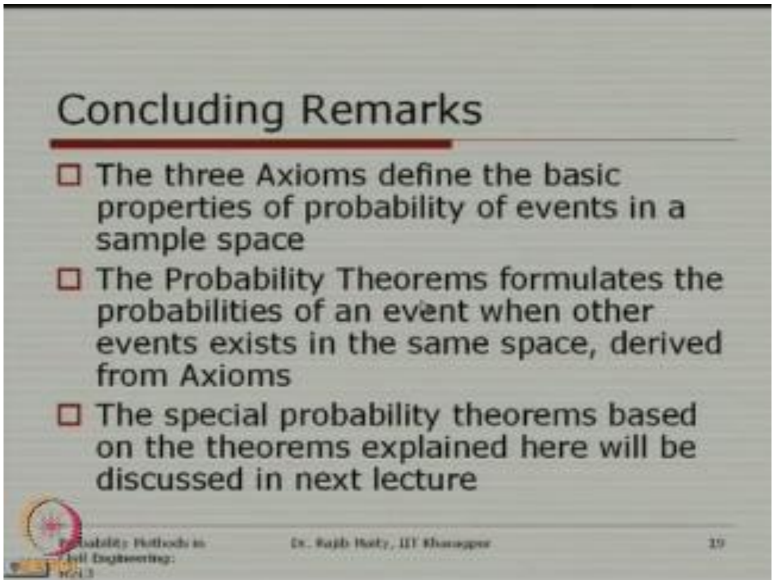

So in this class, we have seen that there are three axioms that defines the basic properties of the probability of events in a sample space and the probability theorems formulates the probabilities of an event, when other exists in the same space derives from this axioms. The special probability theorems based on the theorems explained here will be discussed in the, in next lecture.

But before I conclude I just want to add to one point here. When you are talking about this axiom of this probability, one thing should be kept in mind, that this axiom of probability never tells how we should assign the probability. It only gives some guidelines, that how the probability should be assigned. But, what should be the actual probability of a particular event, it is nothing to do with the axioms of probability. So, if we just see that the last example that, that, what we have done.

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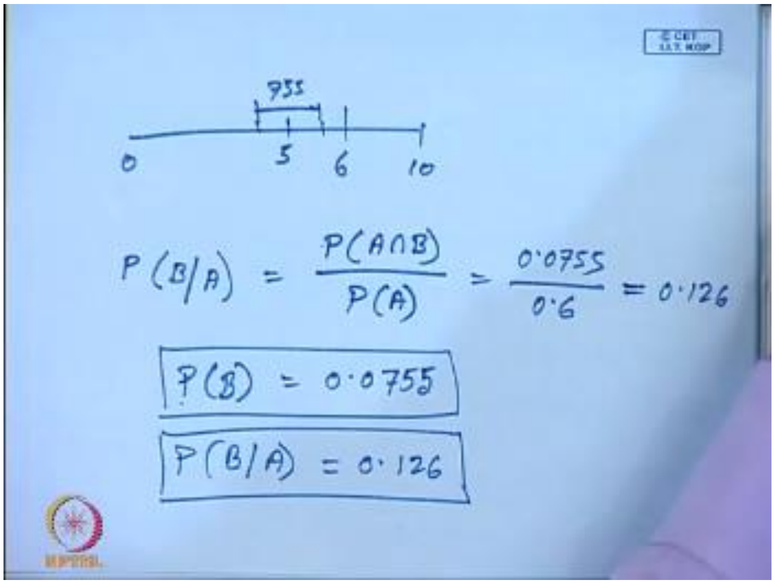

Is that, it is that when we are when we are talking about this probability of B and the probability of B and probability of A or whatever.

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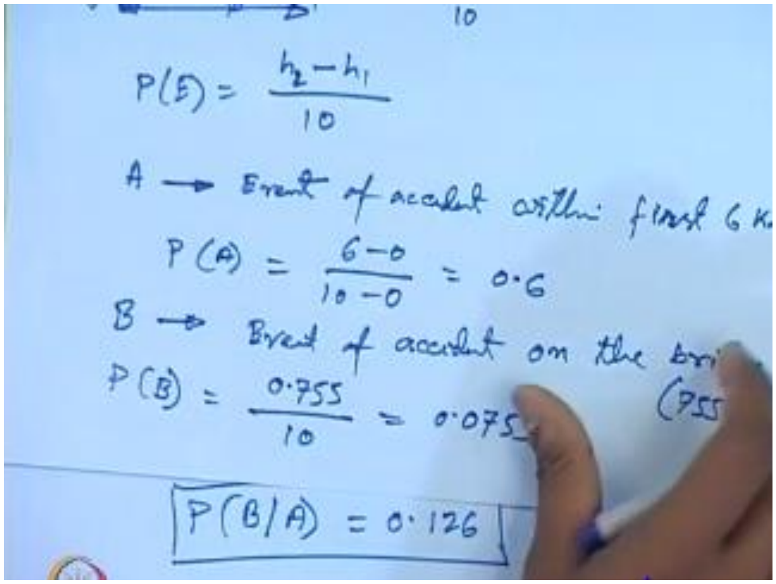

We are just now having seen but these are coming from this, from the equally likely probable events, all these things that we discussed in the last class. Only thing the axioms states that there are some certain guideline that must be followed to get to assign this probabilities. But what should be the actual probability for the particular event is nothing to do with the axioms of probability. So with this I conclude these classes in the next class some more properties and the special probability theorem will be discuss in the next lecture, thank you.

Probability Methods in Civil Engineering

End of Lecture 04

Next: "Probability of Events" In Lec 05

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