Special Theory of Relativity

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Lecture - 1
Problem with Classical Physics

Hello, my name is Shiva Prasad, I am professor of physics, in Physics Department of Indian Institute of Technology IIT, Bombay. And have a pleasure to introduce some lectures on special theory of relativity. I do not think that as far as social impact is concerned, any discovery of physics had such a great impact as special theory of relativity. The relation e is equal to mc square, had essentially become a common name, almost everyone associates Einstein with e is equal to mc square. There have been t shirts, they have been so many things designed with e is equal to mc square, even if you ask a layman, who do not know anything of physics, probably would have heard of equation e is equal to mc square, that was the impact of theory of relativity.

Now, in this particular lecture, I will start, with an introduction of special theory of relativity, would like to mention why it become necessary or why it become important for us to discard some of the old concepts of classical physics. And eventually land up into the theory which is called a special theory of relativity or to be more general- theory of relativity.

So, we will be discussing some of these concepts. Then will actually go to the formalism, of special theory of relativity, we will mention what is special theory of relativity? What are the postulates? And how does it change our perception of the nature. After that we will try to work out few examples, try to explain, the intricacies of what? Einstein postulated, then will go to some other concepts, which are somewhat more abstract concepts, like concepts of four vectors, and eventually land up into mass energy relationship e is equal to mc square, which as I have said just now had a very great impact on almost everyone. Finally we would like to discuss, the transformation of electric and magnetic field, and that is where our course would end. So, this is in a brief, the course of action that we will be doing, as far as this particular course is concerned.

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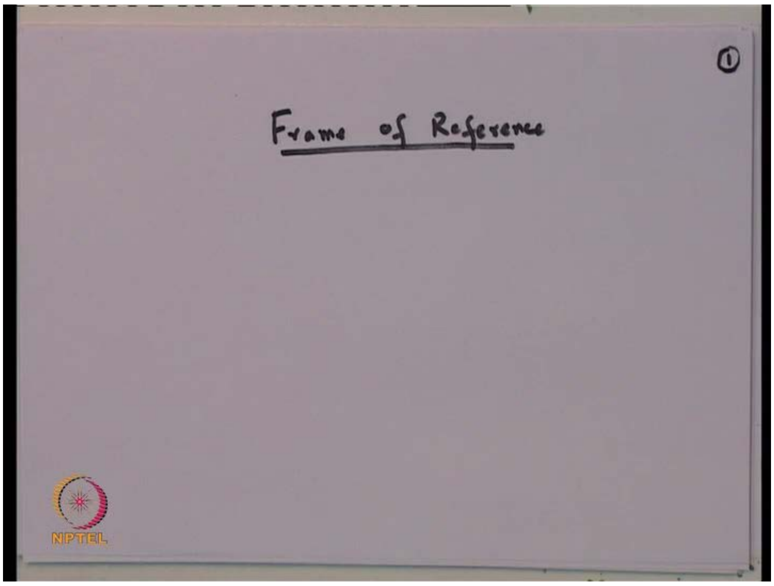

Now before I start let me introduce some concepts, which are short of very common concepts in the classical physics. And one of the most, important things that we have to understand is what we call as frame of reference. I would like to spend few minutes to explain this concept, because my impression has been that many of the high school children are fairly confused about this particular concept. Also they try to mix up observations from various angles, so let us first understand, what I actually mean, by a frame of reference. Well the name sounds big, but actually the concept is very simple, whenever we are trying to make some measurements, trying to understand, trying to speed, to measure the speed, or acceleration, or for that matter, any dynamical quantities. We should be very clear who is observing, and where this particular observer is situated.

So, I assume that there is a person, which is sitting with a watch, and some measure instruments, and has capability of measuring distances, time, and therefore, speed accelerations, etcetera, and this particular observer is fixed, in a given place, wherever we are trying to observe. As we will seen is very soon in the some of the examples, the perception can be quite different, depending upon where, this observer is sitting, or where this observer is located. So, effectively the person, who is making an observation wherever he is sitting, we call that particular place as the frame of reference, let me just take few examples. Let me first explain this little more formally.

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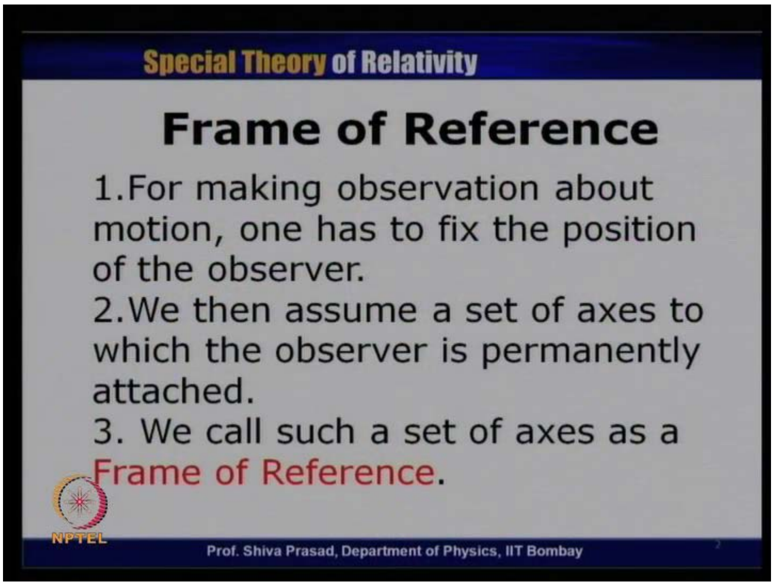

So, this is what I have written, for making observation about motion, one has to fix the position of the observer, this is what I have mentioned just now. We can assume, that a set of axes, to which the observer is permanently attached. We assume that there is exist set of axes, so we know what is x coordinate, we know what is y coordinate, we know what is z coordinate, and he has all the methods of measuring all these coordinates. We call such set of axes, as a frame of reference.

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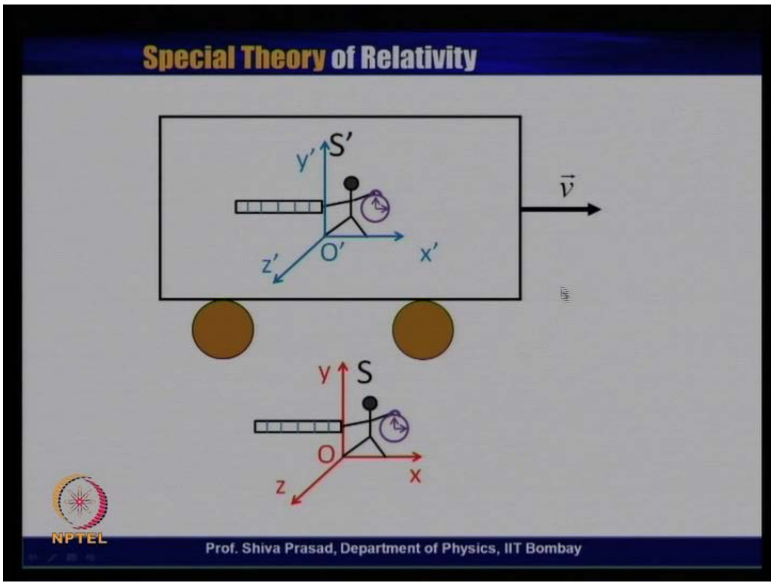

Let us take an example here. I have shown a sort of cart, which can assume something like a train compartment, and something which is like a observer, which is sitting on the ground, this is something, which is very commonly seen, in everyday life. Let us assume that is observer, which is sitting here east or north, and this is a train which is moving, to the right hand side, with a velocity v, as being observed by this particular observer sitting on the ground, which I am calling as S. I assume that this particular observer has a clock here, has a measure instrument. I assume that there is another observer, which is fixed in to this particular train compartment. Let us suppose he is sitting on the particular one of the seats, this particular observer also has a watch, and has also a measuring instruments, but he is permanently fixed in that particular reference, and we assumed that he has all the capabilities, of measuring the distance, remaining fixed in that particular frame of reference.

Now I call this particular frame S, this particular set of axes, and this particular observer has a frame S, I call this as frame S prime. S is the common perception, this particular observer feels, that this train is going towards the right hand side, with a velocity v; that is what we have just now told, but what will be the perception of this particular person which is fixed in to this particular train compartment, this is a very common thing , I thing many of us in our children , I mean our childhood, would have ask the question to our parents, when we are moving in a train; see I see all this trains moving backwards, why they are moving backwards, excepting this similar way this particular person would feel, that this particular observer S is moving backwards with a velocity v. He does not percept, he does not perceive his own velocity, but he perceives, that this particular observer S is moving backwards, with a velocity v. So, what we are saying, is that perception, differs on frame of reference.

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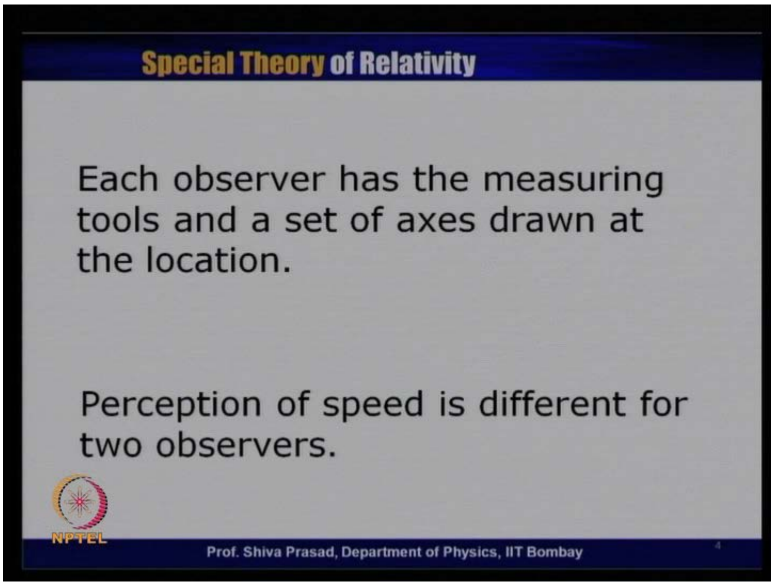

So, this is what I have written; each observer has a measuring tool, and set of axes, drawn at the location, and the perception of the speed, is different for two observers. So, I think we should be now clear that, whenever we are defining a speed, defining a distance, defining a velocity, I fix particular observer, who have given place, which we call as a frame of a reference, and we should never confused between the concepts of the frame of the reference. We should be clear, when I say this is the speed of the particular object, who is measuring that speed, where is that particular observer located, or in other words, what is the frame of the reference, with respect to which these measurements are being made.

So, we have to very clear, we cannot mix up, the speed measured by one frame; one observer in one frame, from the one which is being measured by another observer, in a different frame, so we should be clear about this particular concept. Once we have understood the concept of frame of reference, now let us review little bit, the classical laws of motion, and which I would like to start with Newton's law.

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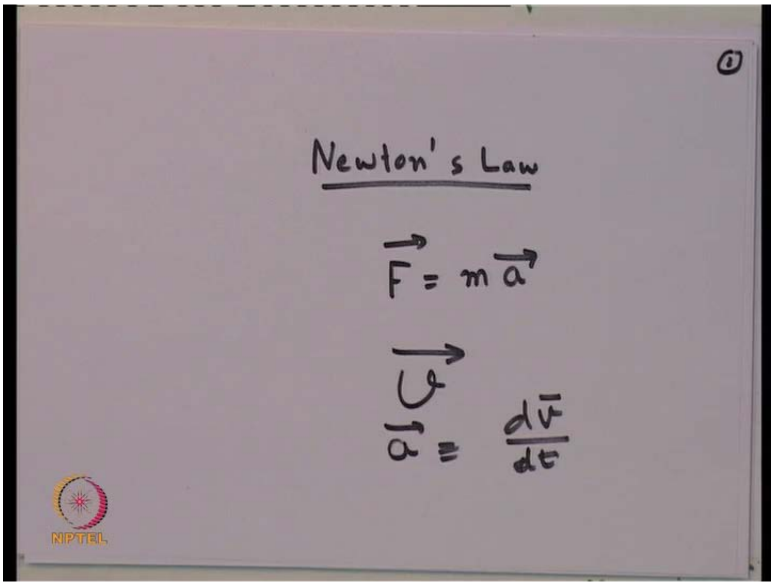

The normal text book will normally we define, we generally give three different laws of motion of Newton, but what, when I say Newton's law here, I would generally mean the second law, because that what is considered as the most fundamental law of Newton, which assist test that force is equal to mass into acceleration. Before I come to this law, let me first go, to the old concept of, what is a natural state of motion. If you go to the old time, very old time, we always thought, that the rest is the natural state of motion. This was not very difficult to understand why people thought it that particular time; that the rest is natural state of motion, because we always find, things to be stationary. Our observation is of course, at that time was fairly limited, and whenever we are see; for example, this particular pen, it is stationary. If I have to make it move, I have to apply a force, then only it moves.

So, it appears that rest is natural state of motion, because even if moves, after some time out again it stops. So, probably every object, likes to stay in stationary state. This particular observation was, believed by large number people, until Galileo, when we had more results of astronomical objects, and we found, that seems that lot of astronomical objects, which seem to be moving, at least as in my earth, or as in my observer earth, without apparently any force of them. So, if as postulated by Galileo, and later put as first law of motion by Newton; saying that it is not at the rest, but a constant velocity v, which is a natural state of motion, puts when you say v by v v v a vector v, which means the magnitude as well as the direction.

So, what postulated by Galileo and later by Newton is that, it is the velocity the constant velocity, which is the natural state of motion, and not really the rest. In fact, rest can be perceived differently by different observer, as I have just now mentioned in the given example. Therefore, what is natural, is having a constant velocity, and why this particular objects stops for example, when I give it a force is not because that the rest is a natural state, but because of the fact, that this (( )) force of this particular paper, which makes it stop. Had this particular frictional force not been present, this particular object would have kept on moving.

So, this is something which was a total different, or total change in our conception, when we realized, that the constant velocity is the natural state of motion, and not just the rest. And then we come to the Newton second law, we says, that in case this natural state of motion has to be changed, it means if the velocity has to be changed, either in magnitude or in direction, then the force has to be applied. So, force would result in to an acceleration, which essentially means, a change of velocity, actually acceleration is given by, define as dv dt, where t is the time. If we differentiate velocity with respect to time, we get in to an acceleration, and this acceleration is given by the force, which we applied to the bottom. So, this is what I have written in some of the next transparencies, let us just look at this.

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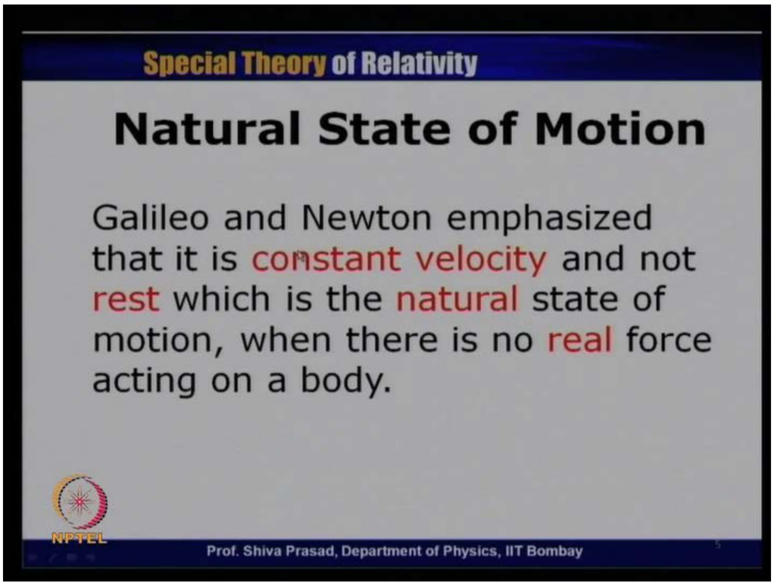

We have said a natural state of motion, Galileo and Newton emphasized, that it is constant velocity, and not rest, which is a natural state of motion, when there is no real force acting on the body.

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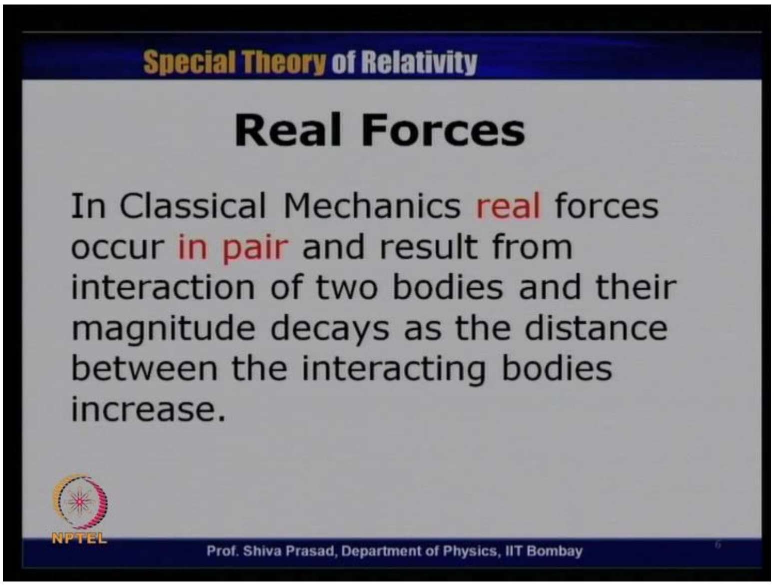

Now let me come to this concept of what we mean by a real force. In classical mechanics, which actually is a result of Arsudan Newton's third law of motion; all the real forces occur in pair, let me try to explain, what I mean by this concept of a pair. If a particular body is experiencing a real force, according to the classical mechanics, there has to be another body, which must be exhorting a force on that particular body. And the body which is exhorting the force on this particular body must also be experiencing equal and opposite force.

Let us consider two bodies, and let us take a simple example of a gravitational force. So, when I say; for example, this could be earth, or this could be any other heavy object, and this is a small object. We know that there is a gravitational force, which pulls this particular object towards this. So, this particular object experience as a force F, towards this body, because of the gravity. What I am saying, is that this cannot a force and isolation, if this body is experiencing, is exhorting a force on this particular body, in the result, as a result, this particular body will also a experiencing force, which is equal and opposite.

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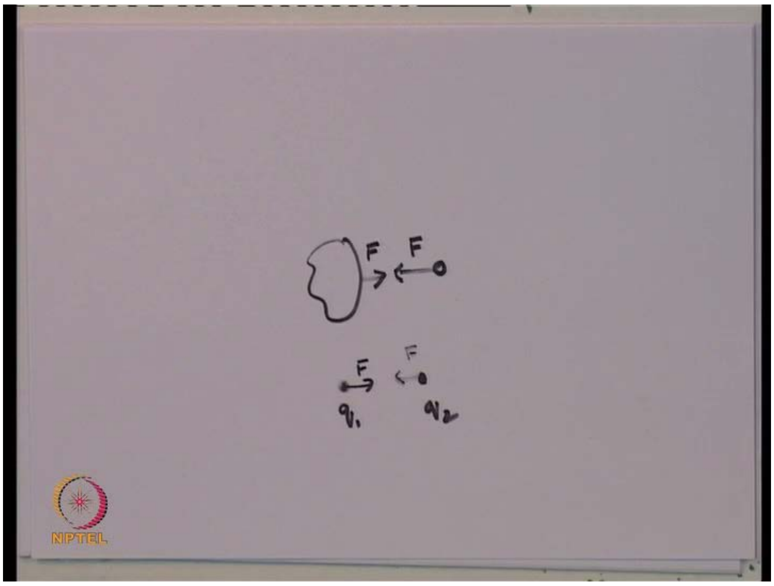

Of course, these two forces act on two different body, this particular force is exerted this particular body, the same force equal and opposite exerted on the other body. So, there are always forces, which are occurring a pair, and they are equal in magnitude, and opposite in direction, this is what we mean by a forces, real forces always occur in pair. So for example, if I drop a body on the earth, this is going down or this accelerating down, because the force of gravitation, cause by earth, then this earth is also be attracted towards its body, by the equal amount of force, in an opposite direction.

The only thing is earth is so big, that the small force, would hardly have any results, or resultant change in the motion of the earth, but this body having a small mass, would experiencing a much larger acceleration. Similarly if you have two chargers, let say q 1 and q 2, and there is electro static force between them. If q 1 is attracting, let us suppose they are opposite charges, so there is an attraction force. So, this particular charge, is attracting this particular charge by a force F. This charge must also be attracted towards its particular charge by the same force F, so all these real forces occur in pair. We do not say a real force, we just act on one body, without having another body on that, causing this particular force. Now the second statement which I make is that classical mechanics we can see, that as the distance between these two bodies, which are interacting, increases the force on this bodies decreased.

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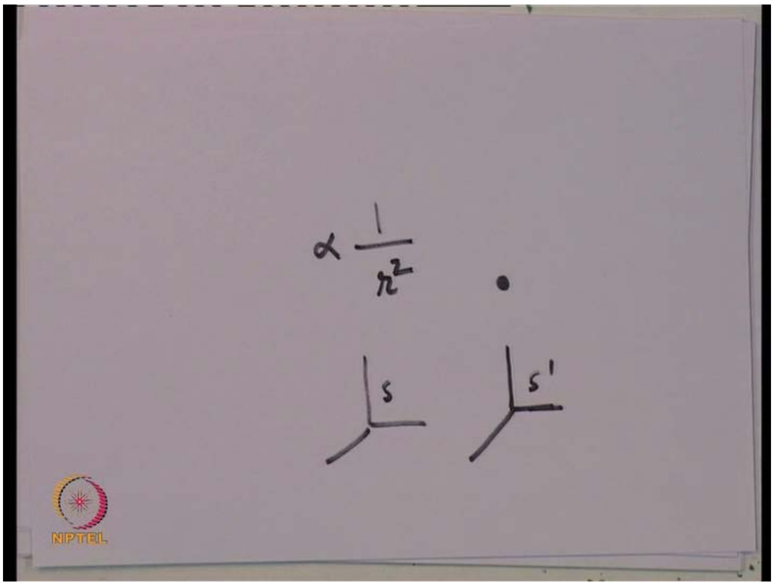

In fact, as we can, we are quite aware, that gravitational force, and also electro static force, who is has one upon r square, is proportion to one upon r square, where r is the distance, between the two bodies. It means if I increase the distance between these two bodies, if I make this body further off, the force of gravitation between these two bodies were go down, as one upon r square. Similarly if I make charges go away, then the force on these two bodies will decrease, as one upon r square. So, these are the two statement which I have making, in this particular transparencies.

In this particular transparency, that in classical mechanics real forces occurs in pair, and result from interaction of two bodies, and their magnitude decays, as the distance between the interacting body increases. Now we come to the concept, of what you called as a isolated object. If you can imagine, that I can take one particular object, really far off from all other objects, then we can assume, that this particular object would not be experiencing any real force. to be more précised particularly, as the distance of this particular object increases, or tends to infinity, from all other objects, then the force tends to zero.

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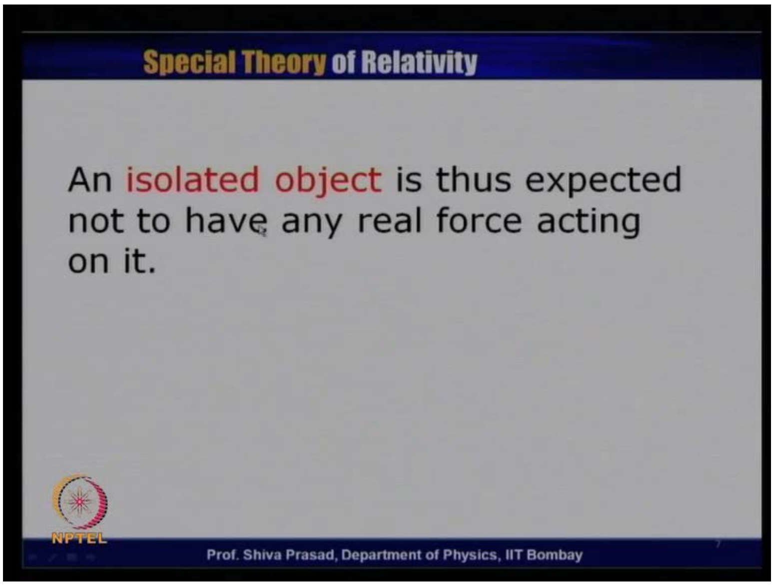

And that is what, I have written an isolated object, thus expected, not to have any real force acting on it. Therefore, if there is no real force, then whatever we have said about laws of motion. Then in principle this particular object, should not be having any force on this. And therefore, should be moving with constant velocity. But just now we have said that the velocity depends on the perception of the observer, so we will define some frames of references which we call as inertial frames.

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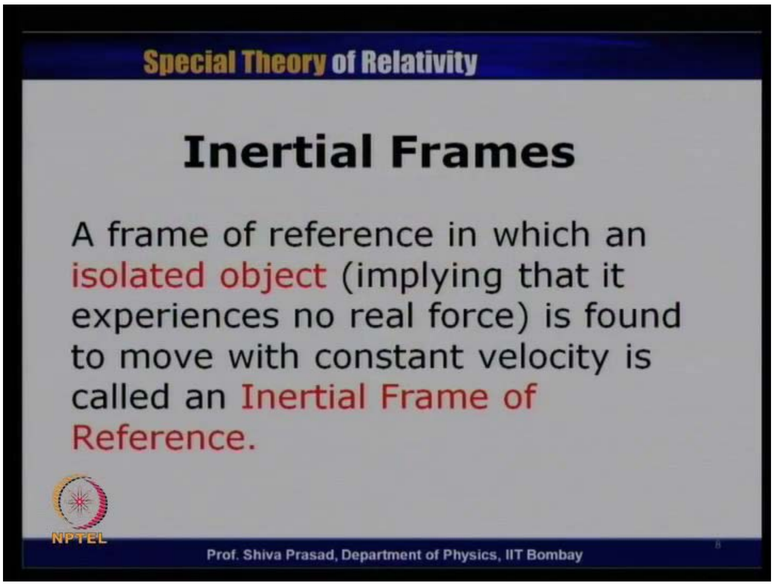

Inertial frames are those, in which this isolated object, appears to be moving with constant velocity. So, let me read this particular statement; a frame of reference in which an isolated object, which implies, that it experiences no real force, is found to move with the constant velocity, is called an inertial frame of reference. Of course, it means that there could be some frames of references, in this particular object, would be found accelerating. Those frame of references are special frame of references, about which I would not be talking, as far as this particular course is concerned, because this course, is actually a course on special theory of relativity, and the word special here means, that we are dealing, only with those frames of references, which are inertial, which we always assume, that our observer is sitting in a frame of reference, in which an isolated object is found to move with a constant velocity. Off course, again I remind, when I say constant velocity, it means both magnitude and direction, not just the magnitude, no way velocity is a vector quantity.

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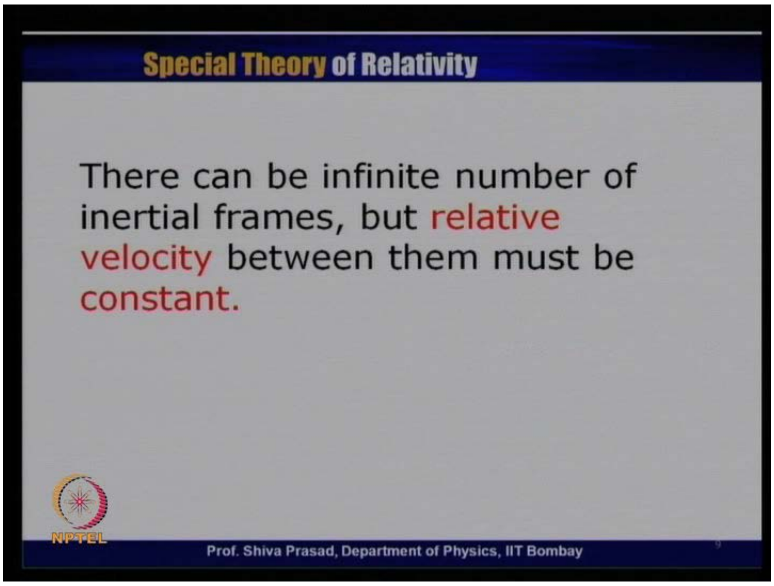

So, let me make this statement, there may not be only one inertial frame of reference, there could be infinite number of inertial frame of references. They may measure different velocity for the same object, which I am assuming to be an isolated object. Their velocities could be different, but what I am assisting, that if the frames of reference have to be inertial, then all of them will observe the velocity of that particular object, to be constant, not very varying time. Of course, the magnitude of velocity could be different for different frames, the example which I have just given, is assuming, is quite clear, that depending upon how will where our observer is sitting, the velocity measure could be different. So, what we have said, that out of all these velocities, though velocity could be different, but they will always find the magnitude, and the direction of the velocity to be same.

I make a further statement, that we have inertial frames of reference, different inertial frames of reference, then if all of them are inertial, then the relative velocity between them, also have to be constant, as a function of time, what it means, that if I have set a axis like this, and I have another set of axis like this, and there is a object, this observer S, observes this particular object, and finds it to be moving with constant velocity. Similarly this observer S prime, also observe this object, and finds it to be moving with constant velocity, then the speed of S and S prime, the relative velocity between them, has also to be constant, because if it varies, then they cannot both observe, the object to be having the same, I mean to be having a constant velocity. As I mentioned that we shall assume that this course, unless specifically mention, observations are made, only inertial frame references, and whenever we are talking about the force, we are always assuming that the forces are real, that was the typical of special theory of relativity, as I mentioned, that special word means, it deals only with special sets of frames, which are inertial frames of references.

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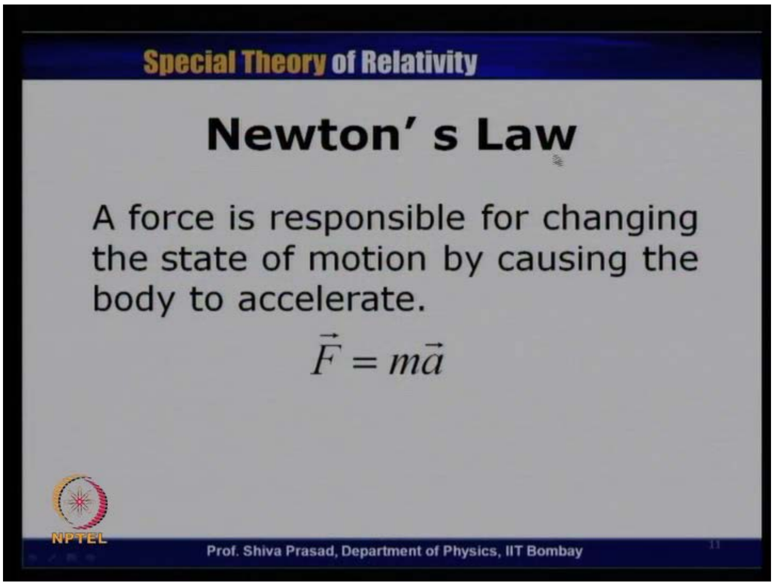

Now, in this particular transparency, I have again described Newton's law of motion, which had mentioned, somewhat earlier, that a force is responsible, for changing the state of motion, by causing the body to accelerate, and this is given by this equation F is equal to ma; remember this is a factor equation. If I apply a force F, and m is the mass of the object, this particular object would accelerate, with an acceleration a, given by this Newton's law of motion.

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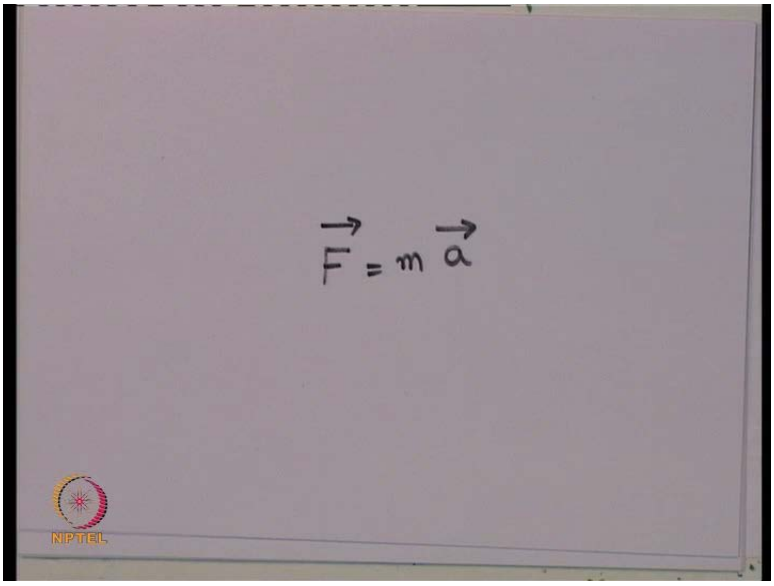

I make another statement, which I would like now to prove, saying that, as far as Newton law of motion is concerned, which I have just written as that F is equal ma. It makes no difference, where our observer is sitting so long, he is sitting, he or she is sitting in a inertial frame, what I mean to say that this particular law, F is equal to ma, will be valid, in all inertial frames of reference. Let us just understand this particular thing little bit more, because we have just now said that velocity is different in different frames. Let us understand how it is so happens, that this particular law is frame independent. It means, irrespective of which frame am observing, this law would be still valid. Let me just take an example here.

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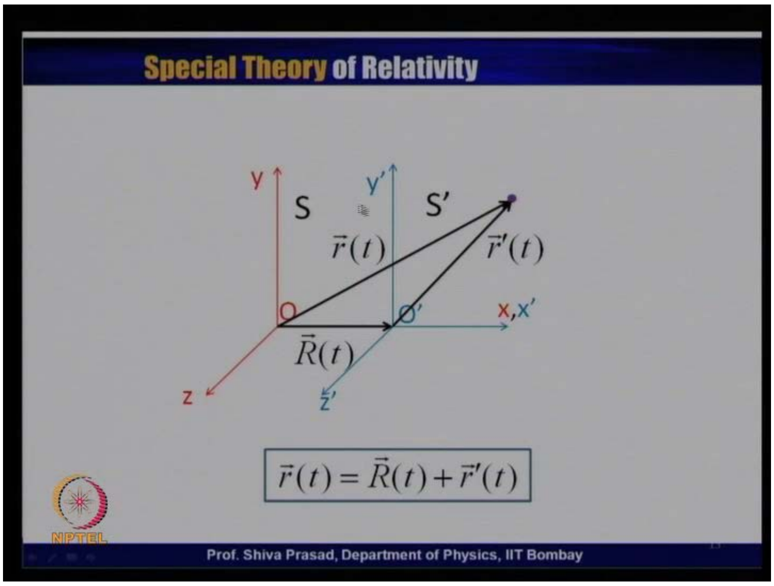

Here, what have drawn, are two sets of axes; one is a blue set of axes, which is am calling is as S prime, another set of axes, which are sort of red set of axes, which are am calling as. It has its own set of axes, for example this is x prime, y prime, and z prime. This has x y and z. I assume both these set of axes, are representing inertial frames. Let us assume that there is a object here, which of course, could be, stationary moving or in general accelerating, or may be accelerating with the constant acceleration, or varying acceleration, I make no particular assumption, as far as the motion of this particular object is concerned. Only thing I am assuming, that S and S prime are inertial frames. Now let us freeze the situation at a given time, and at a given time, the observation is made by both the observers, in S and S prime, about their position.

This observer, red observer which I am calling as frame S, observes the position vector of this particular object to be R t, this is what I have written here R t, at the same time, because the original observer S prime is here, he measures a different position vector, which I am calling as R prime t. So, their position vectors are different, as we change the frame of reference. Of course, we can very easily see from the standard vector algebra, that if the original of this particular frame S prime, is located at the position vector of R. here with respect to the origin of S frame, then this R t must be given by this R t plus R prime t. If I have to reach from particular point to this particular point, I can go this way, and then this way, and will reach this particular point. So, this vector R t can be written, as sum of capital R t plus R prime t. So, this I thing should be clear, that R and r prime would be different, when I change my frame of reference, the position vectors should be different, because their origins are in general different.

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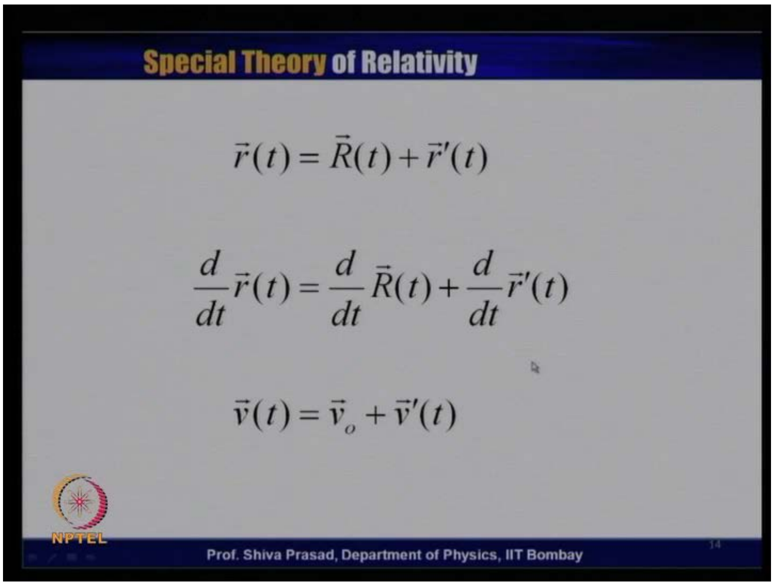

Now, this is what I have written, in this particular transparency. This is the same equation which I written in the last transparency. We have said that all these things depend on time, because I have forcing the situation at a given time. As time changes this position vector R will also change, this will also change, this will also change, because everything is dynamic, they are moving. Now suppose I want to evaluate, their speeds, I must measure in the given time, how much position vector has changed, and to be very precise, I must differentiate with respect to time. So, I differentiate this speed to time, of course, I assume here this particular thing without, making too much of comment at this particular point, that the time measured by the two observers in an S and S prime is same. So, when I differentiate I write d dt, I do not write t and t prime separately, of r t must be equal to d dt of capital R t plus d dt of r prime t. So, all have done is differentiated this equation with respect to time.

And I can recognize this particular quantity, once I take the derivative with respect to time, this particular quantity is nothing but the velocity of the object, so left hand side here, is the velocity of the object. Here is the velocity of the origin of S prime with respect S, so this I am writing as the v not, v not is the velocity of the origin of S prime, with respect to the origin of S observer. This particular quantity, because this observation r prime is being made, in the prime frame of the reference, or blue frame of reference, then I differentiate this with respect to time, I will get the velocity of the object, as will be determined, or will be measured by an observer in S prime frame of reference. So, from this equation I get v of t is equal to v not plus v prime of t. The only thing you have noticed, I have not put here this as the function of t, because just now I have said, that the both these frames of references, are inertial frames, their relative velocity cannot depend on time; therefore, this v not has to be constant.

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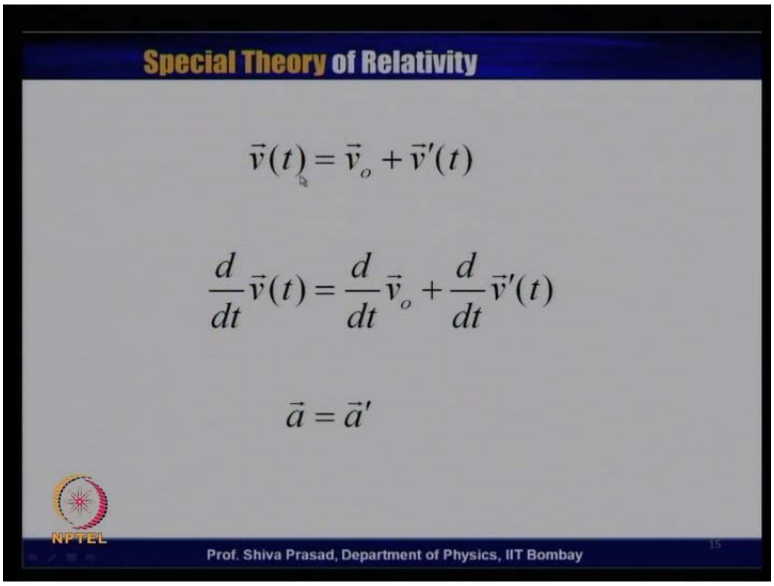

Now I differentiate this particular equation once more with respect to time. So, I have vt is equal to v naught plus v prime t. I know except the same thing, what I did earlier. I differentiate with respect to time both this equations. Once I differentiate velocity with respect to time, all of you know, I will land up in to what is called acceleration of the object. So, this particular quantity on left hand side, will give me the acceleration of the object, as is being seen by an observer in s frame. Similarly this particular quantity, because this v is, which is v prime is differentiated with respect to time, will give me the acceleration of the object, s is being measured in the s prime frame of the reference. I assist that this quantity will be 0, because v naught is the constant at the function of time; therefore, a must be equal to a prime.

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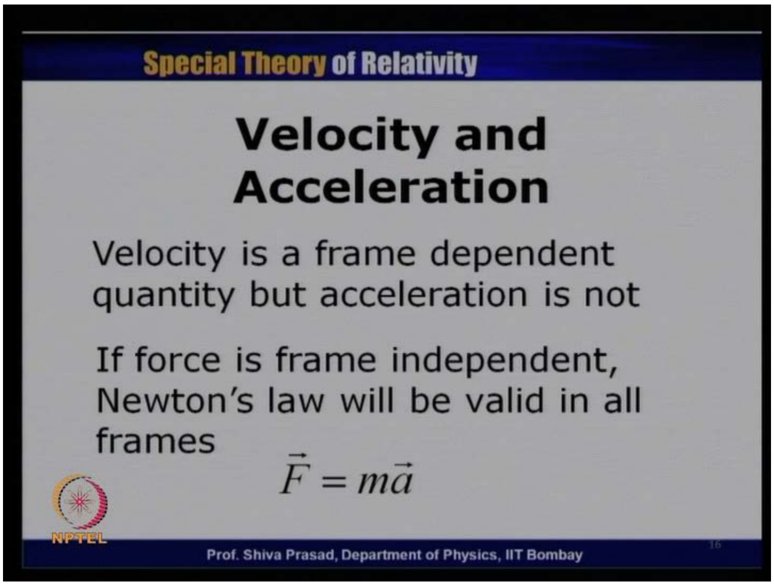

So, we have come to a very important result that though velocity is the frame dependent quantity, but acceleration is not. So, once I change the frame of reference, velocities of the same object, being measured by 2 observers could be different, but if I decide to measure their acceleration, the two observers s and s prime would agree, that the accelerations are same, so now, I come back to Newton’s law of motion. I agreed we discussed that this a same, for all inertial frames of reference; therefore I did when I give acceleration of the object, I did not define my frame of reference, I can say that, this is the acceleration of the object. So, long I am talking of course, only on inertial frame of reference. Now if F, is also a quantity which is frame independent quantity, then F is equal to ma, will be valid in all inertial frames of reference. The velocities could be different in different frame, but the force and acceleration would be expected to be same, and therefore, Newton’s law of motion is equally applicable, in all inertial frames. So far its good, as far as all mechanical forces are concerned, we are quite happy about the situation, because for example gravitational force, is expected to be independent of force, but we have some problem, when we come to an electro electromagnetic theory, let us see.

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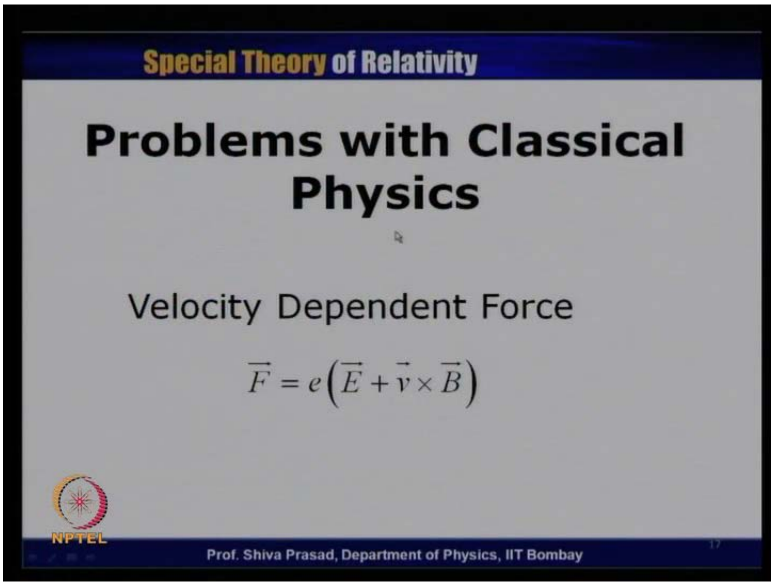

This is what I classified, as problem with classical physics. We just now said, that I expect the force to be frame independent quantity, but velocity is not a frame independent quantity, velocity depends on different frames, even though they are inertial. let us look at the standard expression of what we called as the Lawrence force, if there is a particular charge, which is e, and if it is put inside a electric and magnetic field, the force on the this particular charge, the electromagnetic force on this particular charge, which was also called as Lawrence force is given by e multiplied by E, where capital E is the electric field plus v, v is the speed of the of the charge, cross it is a vector product B, where B is the magnetic field of the object. So, this force of we see, it depends on the velocity, it means if I go to different frame, I will find the charge moving with the different velocity, and therefore this particular force which I am seeing; the Lawrence force, would also become different.

Some of few may ask this question, and rightly so and this question probably a very good and genuine question. After all what is magnetic field, magnetic field also arises, because of the motion of the charge carriers. So, if I go to a different frame of reference, the charges which are the motion which is passing the magnetic field. They will also move with a different velocity. And therefore, probably B is also could be a frame dependent quantity. The answer is yes, this is correct, but the fact is, that the transformation as I go from one frame to another frame, of electric and magnetic field, is also eventually obtained only from special theory of relativity, the correct transformation law. So, let us leave this example as of now. I just wanted to mention this appears to be one of the problems, let us go to a better example. In earlier 19th century, or before that the Maxwell have put down a set of equations, which are called Maxwell's equations.

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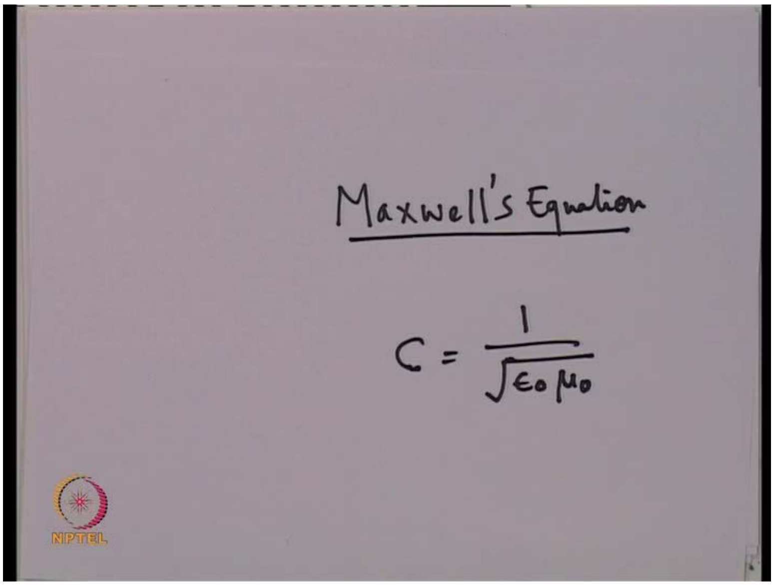

Earlier there has been, some worries or doubt, about what is light, but it was the set of Maxwell's equation, which eventually I would said proved, that light is electromagnetic wave. And eventually he obtain an expression, which is C is equal to 1 upon under root epsilon not mu not, when epsilon not mu not are fundamental constants. According to him, the speed of light, should be given by this particular expression, if it is an electromagnetic field. The speed obtains from this particular expression, mashed with the experimentally evaluated speed of light. Essentially it is conformed that light is actually an electromagnetic field.

So, this is what I have written; the speed of light, depends on the fundamental constants; c is given by one upon under root epsilon not mu not, this is what we have obtained as a result of electromagnetic theory, which had found a very strong hold, at strong footing, in our classical physics. In fact they are two pillars of the classical physics; one was based on plutonian mechanics, and another was electromagnetic theory. Now let us come back to familiar concept of relative velocity about which, we have been talking quite bit.

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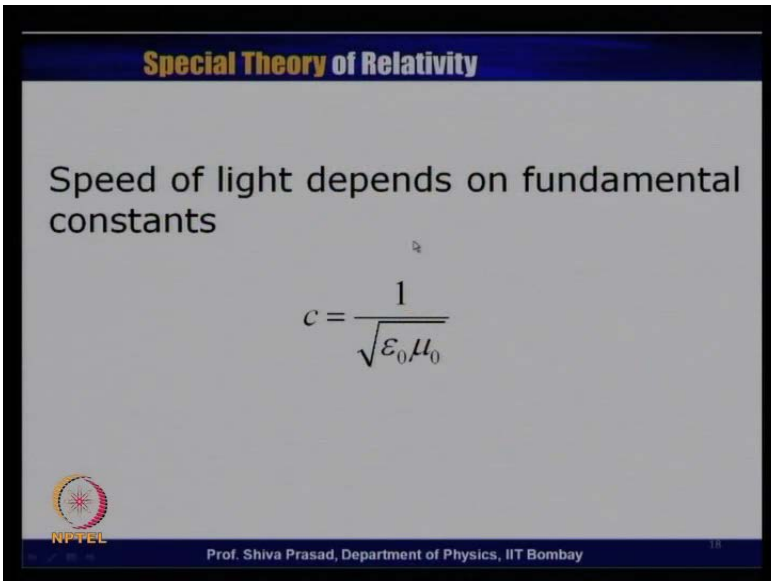

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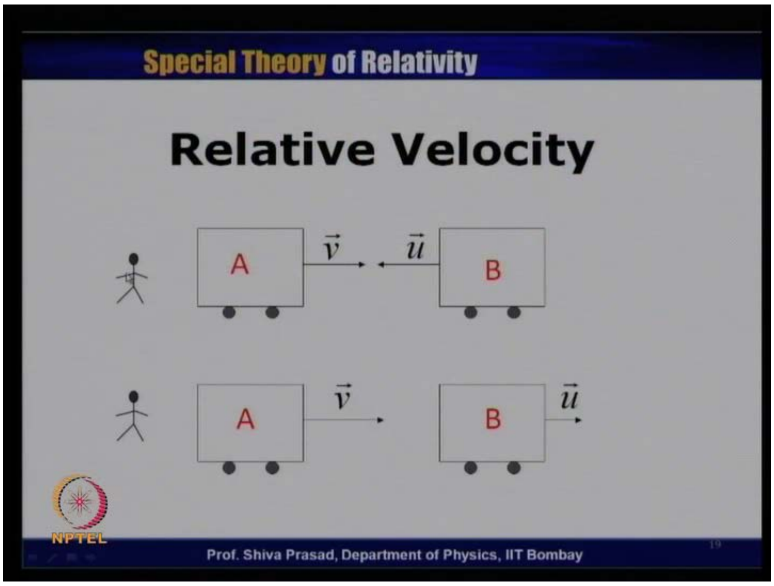

Let us assume that there is a observer on ground, let us assume that this ground is in inertial frame. It observers observes two different train compartments; one train is moving to the right, with the velocity v. Of course, all these velocities are with reference to this particular observer, which is standing on the ground. He finds another train moving to the left, with the speed u, or with the velocity u. Now if I change my frame of reference, and I assume my observer to be sitting here, on this particular train A, as all of us know, this particular person would experience, as it this particular train is moving with must faster speed, and of course, if he assume that v and u are in are along the same line, this speed of the compartment B, or the train B, as seen by an observer A, will be addition of the two, it will be v plus u v, if we feel a much larger speed.

This is very common thing, if we are sitting in a train, another train passes by your side, you find that is moving, with a very large speed, the relative speed just add up. Look at a contraction situation here, the second diagram here. Again these speeds are with respect to an observer, standing on the ground. This is the velocity v, which is trying to overtake this particular train v; for example, a car overtaking another car. The velocity of the, this particular train or car, with respect to this observer v and, of this particular car with respect to this observer is u. Now if am I fix my frame of reference, here let see on B, I will feel that this particular A, is approaching to backwards B, not with speed v, but v minus u, this speeds are differences, the velocities have the differences of the two velocities. This is a common concept of relative velocity.

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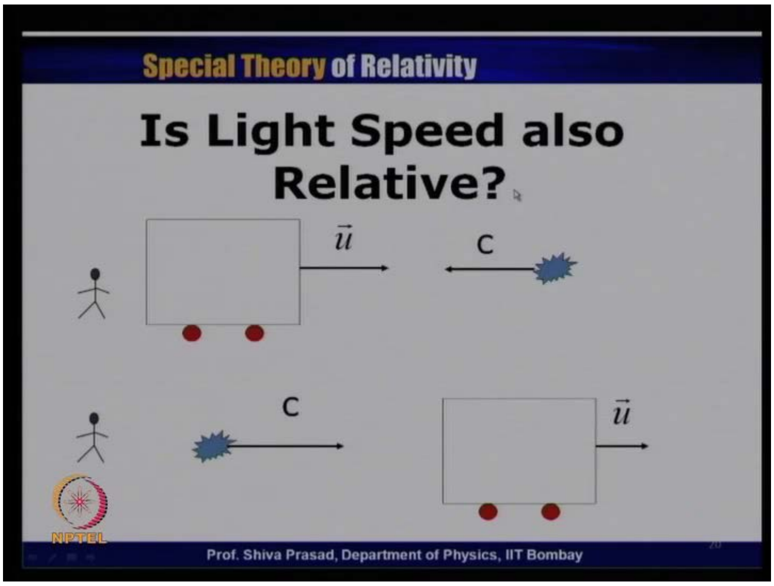

Now, let us look into a very similar and parallel situation, which I have given in the particular figure. All I have done, is that one of the compartment I have replaced, by a light source. My observer is still fitted here, fixed on the ground. He finds that this particular speed, this particular light, travels towards him, with the speed c. While this particular train, moves to the right, as in from him, with a velocity u.

Now, if I assume the same thing, what have I done in the previous example. If I change my observer, if the observers are sitting here, he would find that this speed will be c plus u, exactly taking parallel, what we have discussed in the previous example. Similarly, if the train was moving like this, and the source are, to the right, and the source of the light was here, emitting light in this particular direction. And if this observer finds this speed to be c, and this velocity to be u, then if I change my observer to this particular compartment, he will find that the speed is c minus u, this speed will be less. So, like we do in a normal classical mechanics, the observer here, the observer here, and the observer here. The observer here, the observer here, and the observer here, all three will find different speeds of light; is it correct, will this really happen.

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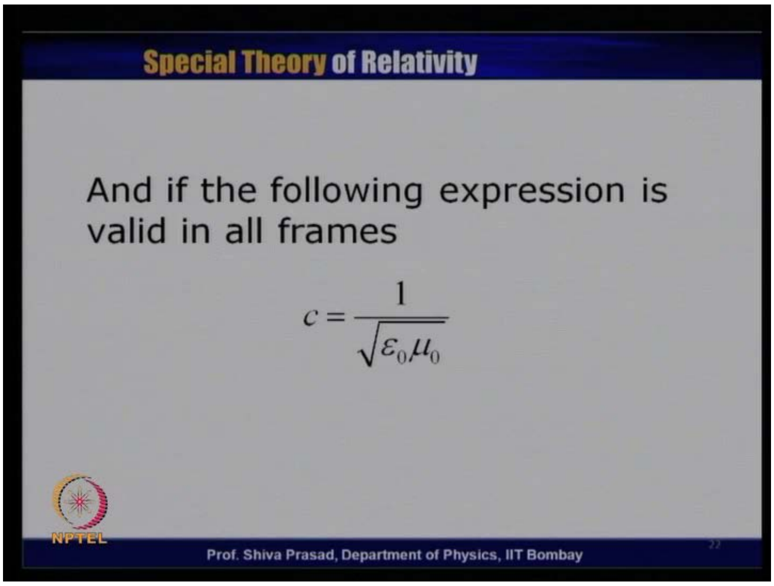

Let see, what is the impact of this, what happens to my expression which have I just now written; c is equal to one upon under root epsilon not mu not. Now, I assume that this expression is valid on all this frames. See remember, we talk to three different frame, three different examples; person sitting on the ground, in a compartment here, and compartment on the other side. If all the three observers, will they still, are they still allowed to use a same expression of c is equal to one upon and root epsilon not mu not, if they are allowed, you just now seen the c is different for all the three observers, and if they are allowed to use this particular observer, this particular example, for a change, have epsilon not and mu not changed.

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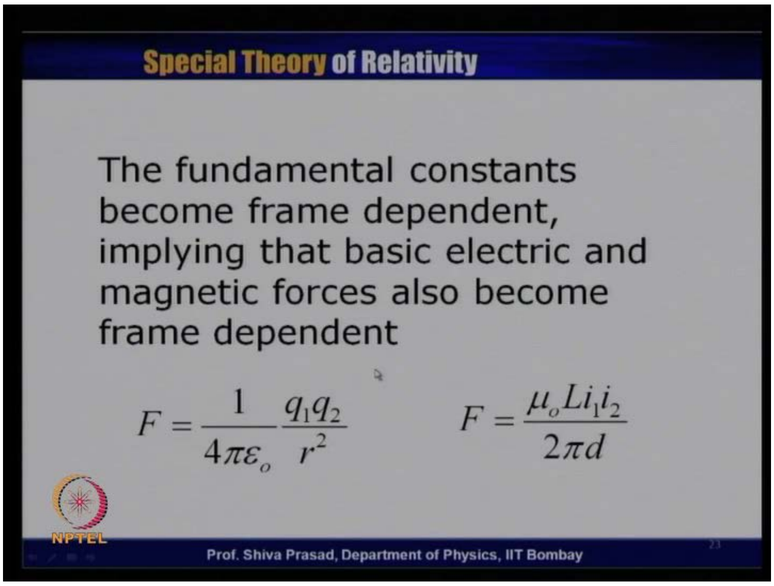

Then do we say; that this particular quantity epsilon not and mu not, have become frame dependent, it means if I go to different inertial frames, then I would notice the different epsilon not, and different mu not, but remember this epsilon not and mu not, are related to the basic electromagnetic forces. See remember this expression, this expression gives the force between two charge carriers q 1 and q 2, and here there is an epsilon not. This expression gives, the force between two carriers two current carrying conductors; i 1 and i 2, and this force is governed by this particular constant. If I say, that this mu not and epsilon not, are different in different frames, do I mean to say that this forces also different in different frames. I have a problem, I do not understand it fully.

There could be another set of argument. The other set of argument could be, that the expression which have just now said; c is equal to one upon under root epsilon not mu not, this expression is not valid in all the frames. This expression is valid only a certain specific frame, this is a second example. So, remember a first example we said; that is the special is valid in all the inertial frames, but then I have to incorporate the fact; that epsilon not and mu not, would be different in different frames, if the speeds of light measured by different frame of references, turn out be different.

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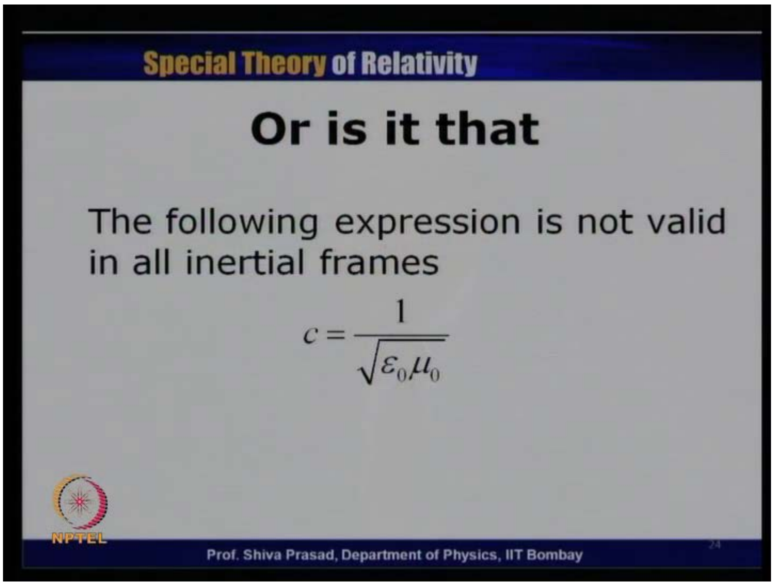

Second example as I said is, I assume that know this expression is valid, only some special frames, not in all the frames. So, then I am saying, that though classically we have said, from Newton's law I have said, that makes no difference where I make observations, so long the frame is inertial, this may not be true for electromagnetic theory. Means from electromagnetic point of view, all inertial frames, need not be equivalent. There is one special frame of reference, in which this expression c is equal to one upon under root epsilon not mu not is valid.

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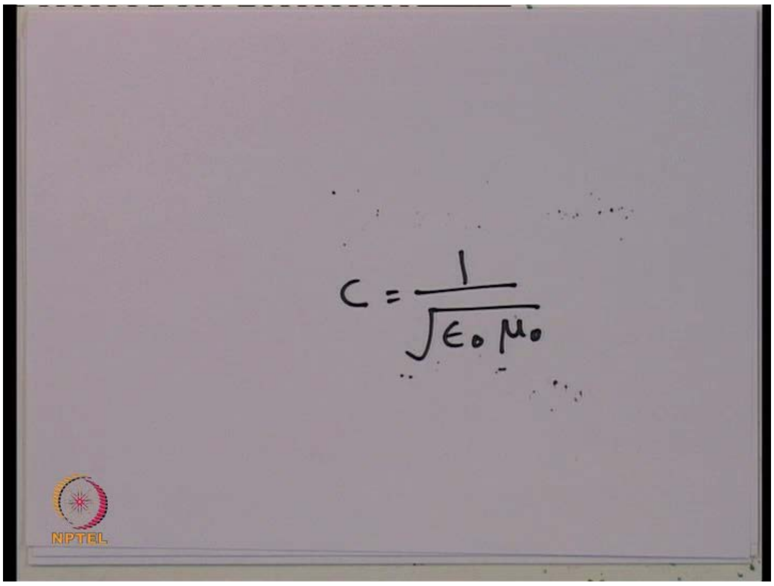

What I am saying, is that the validity of this expression, is only some specific frames. In other frames, this expression is not valid, this is the second example.

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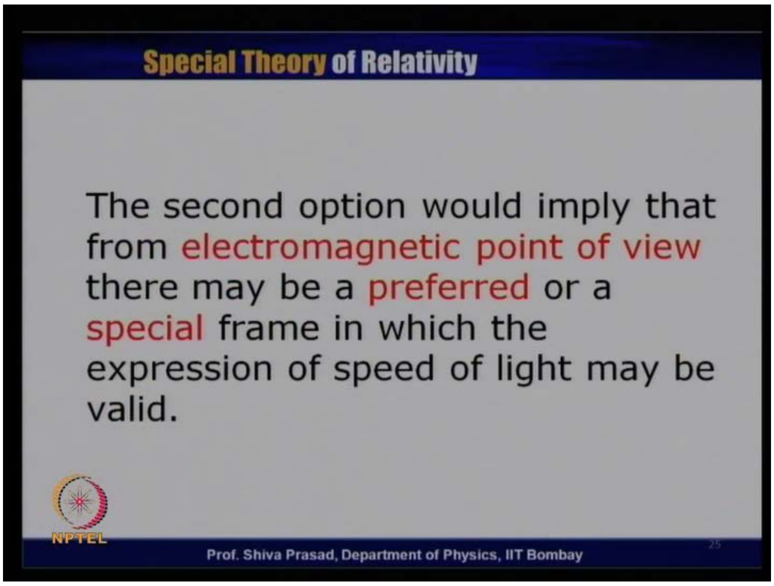

So, I have written here, the second option would imply, that from electromagnetic point of view, there may be a preferred or a special frame, in which this expression, of c is equal to one upon under root epsilon not mu not may be valid, it is not valid in all other frames.

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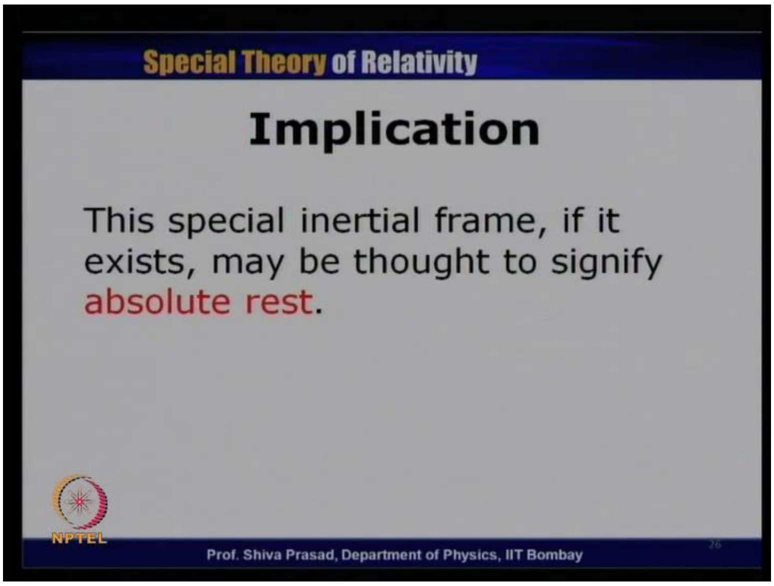

I will extend this particular thing little bit more, and I say, that this special frame I can say is probably signifying an absolute rest. By the way the concept absolute rest, looks at least for a classical physics, somewhat genuine, let us take an example. I would first say that the classical people, is not prefer this particular idea, because it has some sort of examples lets have which I discussed, some of the things that we assume. See we like an ocean, in ocean all the fishes, and all they you know the sea animals, sort of float inside in the sea. I can assume that entire universe is filled with some sort of fluid; of course, this fluid has to be given very special properties. For example, it should be essentially hundred percent transparent, because we can see the light, which is coming from long distances. Probably it has essentially 0 density, because we never able to observe, and of the fluids, but let us assume that the some sort of fluid, see somewhat naturals for a classical physics, which fills entire universe. Classical physicist at that time call this particular medium as ether.

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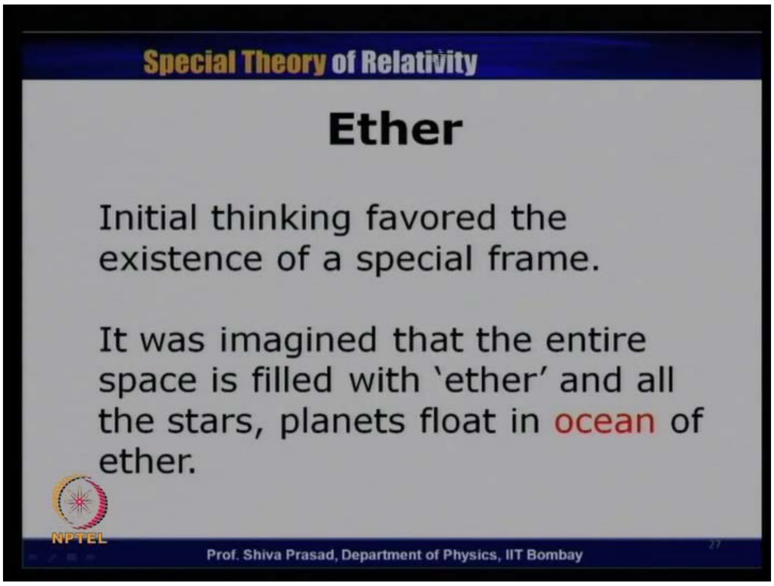

So, they evolved the concept of ether, and they said, that this ether, fills the entire universe like an ocean, the water fills in entire ocean. Similarly everything is filled by ether. We are actually living in ocean of ether, and all the planets; earth, sun, galaxies everything move in this particular, the float in this particular ether. As I said, for classical physicist, is also found another support. See when I talk of traditional waves, with fish. The fish is very familiar from formulated sound wave, when I say the sound wave has a particular speed, with respect to what we talk of the speed. Who measure that speed, and it is always implied, that this speed is measured, with respect to medium in the sound travels. You can all, you all probably aware, that it requires a medium for sound to travel. So, when I say the speed of sound is this much, I assume that the observer is stationary in this particular medium, and the speed of sound is being measured, with respect to the observer sitting stationary in the medium. The speed of sound is given, relative to the medium, but light apparently does not seem to be travelling in a medium.

We see light coming from very far of stars, and apparently there is no medium in between. So, classical physicist did not like this particular idea, after all the wave, requires a medium to travel, sound requires, all the waves that we are familiar, water wave, when we talk about with respect to the water, when we are talking about all these waves. Probably there is a medium, which it should be travelling; it is a different thing that I am not able to see the medium. This medium must have very special properties, but I am not able to observe it; that is the different question, but probably a medium exists. So, the concept of ether found, support from that particular concept; saying that the medium in which is light travels and actually ether medium, and when I say c is equal to one upon under root epsilon not mu not, this particular expression, is true only in this ether medium. So, I can say, that the ether signifying absolute rest, because this is filling the entire universe, all the planets, everything including light, travels into this particular medium. So, this is what I have written here.

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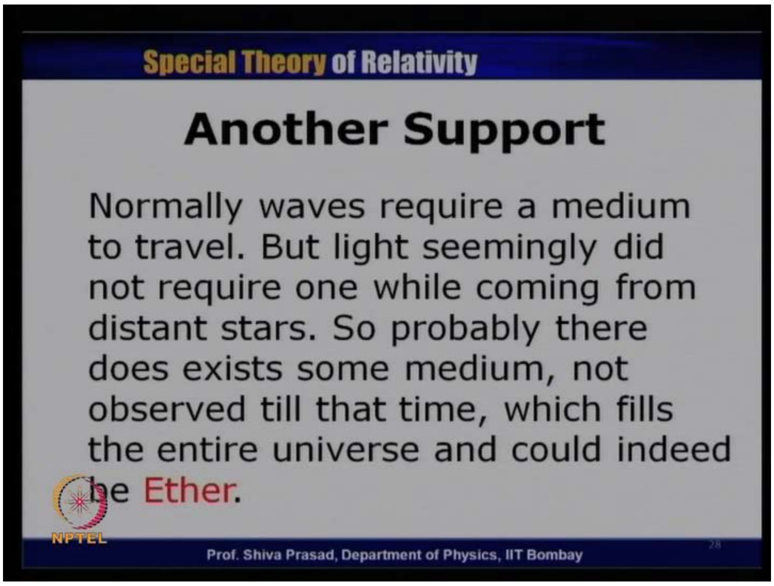

Another support; normally waves require a medium to travel, but light seemingly did not require one, while coming from distant stars. So, probably there does exists some medium, not observed till that time, because it must have some special properties, and this particular medium could be called ether.

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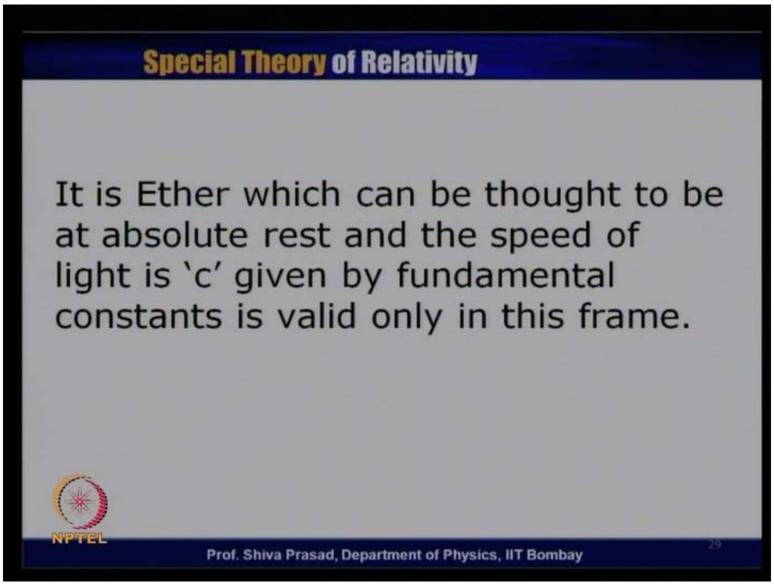

It is this ether, which can be thought to be signifying absolute rest, and the speed of the light in this expression, which have written, must be given, only in this expression, only in this particular medium, only in this particular special frames of reference, frame of reference called ether. If I change my frame of reference, go to another inertial frame of reference. We discussed, then I must measure different seen, if everything of classical physics is valid, but I have said that the expression c 1 upon under root epsilon not mu not, is valid only in that some special frame, I will measure a different speed, therefore I can talk of what is the absolute speed of that particular frame. So, I can signify, I can associate, a absolute speed, with every inertial frame of reference, so this is what I have written.

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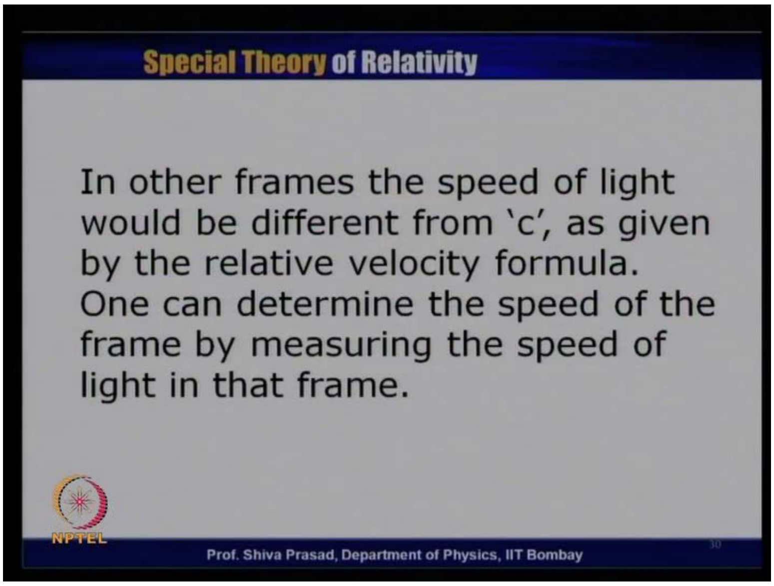

In other frames, the speed of light would be different from c, as given by the relative velocity formula. One can determine the speed, by measuring the speed of light. So, if I measure the speed of light in a frame, and find it to be different, from this expression, I can find out what is my speed relative to ether.

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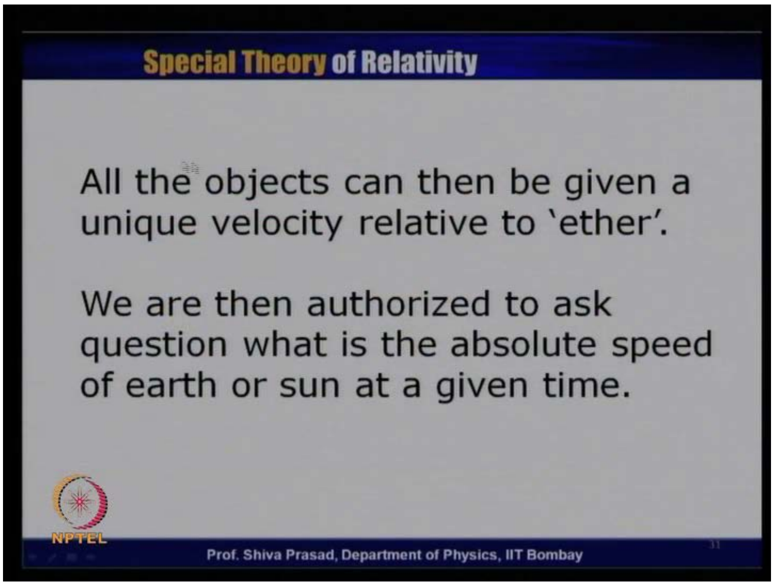

Therefore, I write again, all the objects can be given a unique velocity, which is relative to ether. Therefore, now we are authorized to ask the question, what is absolute of speed of earth, what is the absolute speed of sun. So, again we have mention, that if pure classical physics, velocities frame dependent quantity. If I change my frame, we will change, but a will be same, but now with respect to the special frame, I can always think, that I can also talk of absolute velocity, I can ask question, that the velocity of the object, is how much, or velocity of earth at a given time, is how much relative to the earth.

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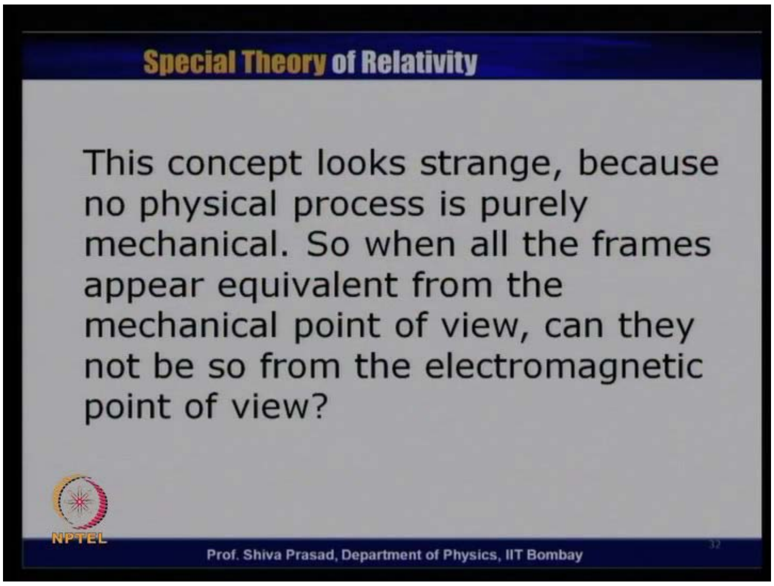

This concept looks somewhat strange, because no physical process is purely mechanical. So, when all the frames appear to be equivalent, from the mechanical point of view, can they not be so from the electromagnetic point of view. Here we have some sort of uneasiness, strictly speaking no process is hundred percent mechanical. See if we are observing two bodies to collide, which are purely to be mechanical process, but the light has to go there, it reflected come to our eye before we are able to observe it. So, there is always mixing of electromagnetic, and the mechanical concept, it does not sound the hundred percent comfortable when we say, that all the frames of references appear to be equivalent, from the point of view mechanics, but not so much, from the point of view electromagnetic theory. We feel some sort of that uncomfort, that why it should be so. What we do, we need experiments. So, this is a point, where we are having some sort of deadlock, though things seem to be somewhat consistent from the classical mechanics, but we still have some sort of uneasiness, let us look, whether we have an experiments, whether we can prove that ether exist.

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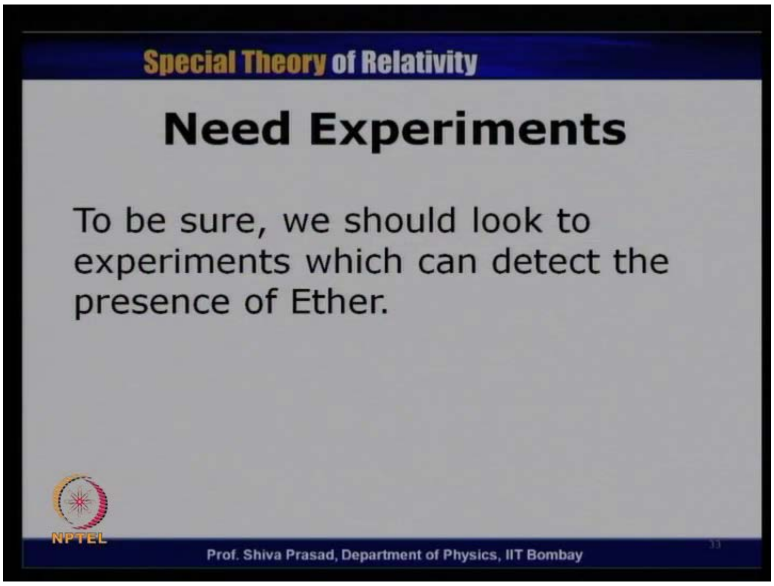

So that is what I have written here; to be sure, we should look at the experiments, which can detect the presence of ether.

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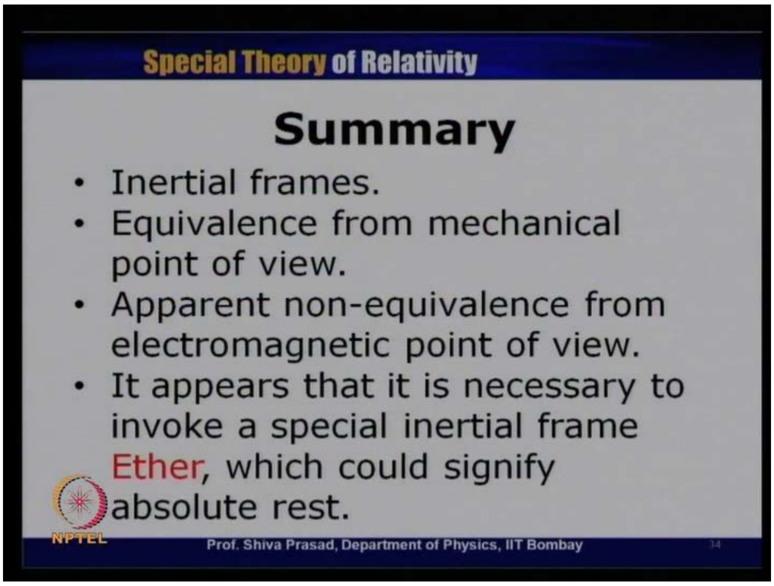

So, in our next lecture, we will be discussing, what are those experiments, and whether it first possible for us to detect ether, before we go ahead. Now, let me summarize what we have discussed, in this particular lecture. We have discussed the concept of inertial frames, we have described what I mean by inertial frame of reference. We have mentioned that, from mechanical point of view, the inertial frames are to be equivalent, but once I go to electromagnetic theory, there appears to be non-equivalence, it means the appearance that there is some special frame of reference, which is necessary to understand the physics consistent. Then finally, we have evolved the concept of ether, and we have said that is a special frame of reference, like ether should be, we should invoke the concept of ether, if we want to understand everything, classic from the classical point of view consistently, though we still have some sort of uncomfort, in this particular idea, because it does tell, that from mechanical point of view, all the frames seem to be equivalent, but from electromagnetic theory they are not.

Thank you.