Select/Special Topics in Classical Mechanics

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Module No. # 06

Lecture No. # 19

Special Theory of Relativity (i)

Greetings, we will begin with a new topic today and this is a very exciting one on the theory of relativity.

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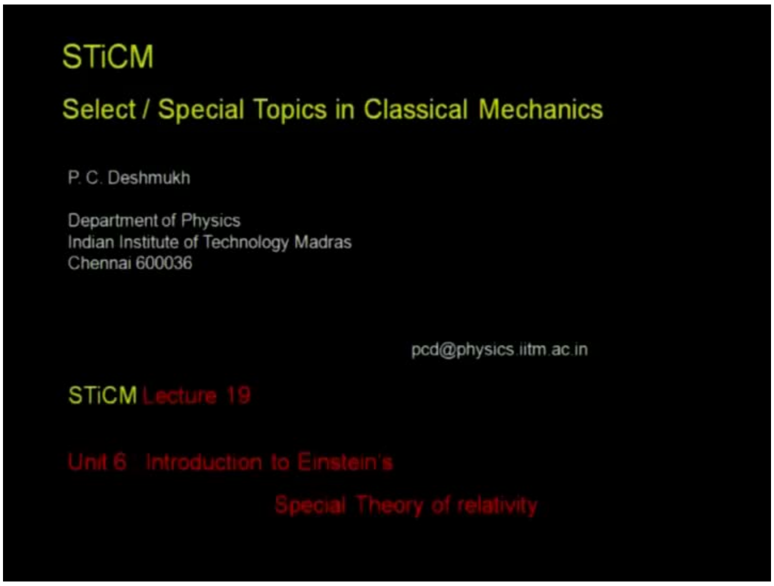

Einstein's name is intimately associated with this theory for good reasons, means he made huge contributions of physics. So, in many branches of physics, for which Einstein's work turns out to be pioneering in respective areas and this is certainly one of those.

This topic, we will cover in about four lecture hours, the subject is vast. Regardless, it shall be my endeavor to give a gist of the essential ideas, introducing you to the special theory of relativity. I have chosen to incorporate this topic in this undergraduate course, which is given as one of the first courses after high school, because as you will realize, the consequences of the theory of relativity are crucial for almost every scientific engineering and technological endeavor.

So, all scientists, physicists, chemists, material scientists, engineers, they all need to have a reasonable familiarity with the theory of relativity, which is why it needs to be introduced at an early stage of education, which is why this topic has been incorporated at this stage.

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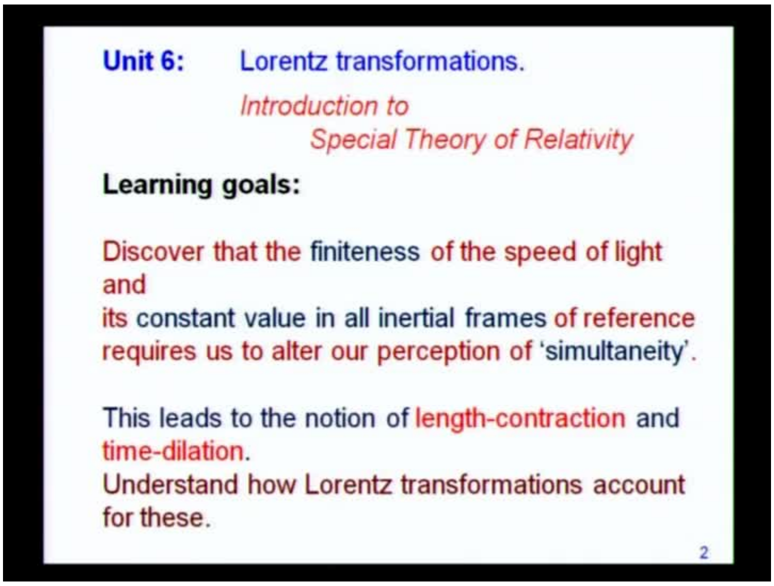

Our learning goals will be relatively modest, but we will discover that the speed of light being finite has important consequences on our understanding of space and time. Finiteness of the speed of light is something that we do not always really recognize in our day to day experience, because the moment you light a candle, you see the light.

It is so fast, so rapid that the idea is that there is something called as the speed of light, is almost alien to human experience, because we think that it is almost instantaneous. We think of speed, when we think about an object in motion - you and I are walking, you faster than me, but nevertheless there are speeds that we talk about or we talk about speeds of people running or vehicles, different kinds of vehicles, cars, aero planes, jets at different speeds, but it is in the context of such objects, motion of such objects that we talk about speed.

That it is an idea, which has an important implication in the context of light, is something that we do not normally think about, we will learn that this is an important consideration. What it will forces to reconcile with is, what we regard as simultaneous also has to be reinterpreted. Because, the notion of simultaneity has almost some kind of an intuitive meaning in our minds, which to all of us, although we do not define it in objective terms, is almost equivalent. Whenever one observer thinks that two events have taken place simultaneously, almost any observer in his vicinity would arrive at the same conclusion that those two events are simultaneous, regardless of the relative motion between these two observers. What we will learn is that this intuitive idea simultaneity needs to be refined, so we will discuss that.

What this will lead us to is the notion that what we call as length, this is between the tip - this tip and this tip. Also, what we talk about is time interval, like the time you took to come to the class from whenever you started.

From wherever you started, you covered a certain distance in a certain amount of time. That gives you your perception of what you interpret for yourself, as your length interval and your time interval. We grow up through our schools and high schools, thinking that this notion of length and time interval is essential of the same for each one of us, regardless of our state of relative motion with each other.

Now, this idea also has to be defined. We will then learn about Lorentz transformations, how this account for the consequences of the special theory of relativity, these are actually consequences of the wave nature is and not consequences of a given theory. The theory itself is a consequence of the laws of nature, so we often say that there is length contraction because of the special theory of relativity. Now, there is length contraction, because that is how nature can best be understood, it is a special theory of relativity which tells us how it needs to be understood.

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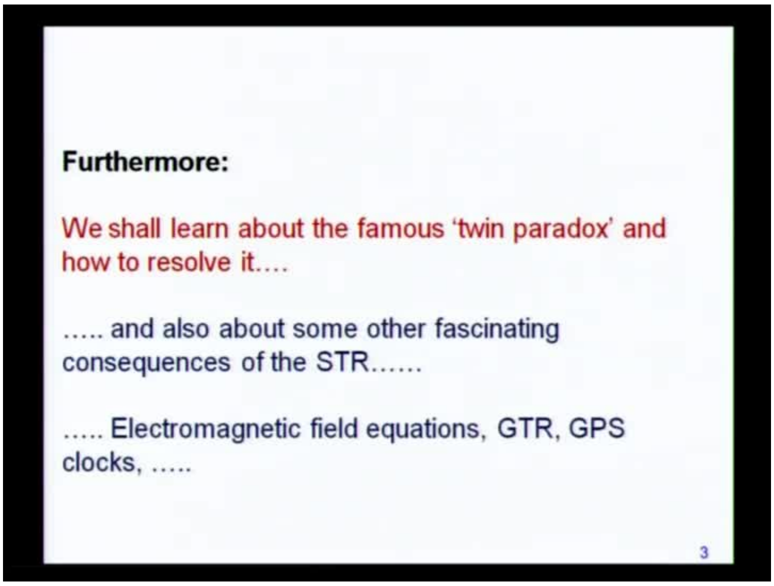

So, we will learn about Lorentz transformations, how these accounts for length contraction and time dilation. I will illustrate these ideas of length contraction and time dilation with the reference of a rather exciting problem, which is rather famous, it is famously known as the twin paradox. I will come to that presumably in the third class - third out of the four class hours that I intend to spend on this.

Then, I will also introduce you to some other fascinating consequences of the theory of relativity. Like I mentioned, the subject is vast, it shall not be my endeavor to go beyond these modest goals. There are important implications leading to electromagnetic field equations that there is this general theory of relativity. I will make a few remarks on how this affects the global positioning system and so on, how this affects our day to day life.

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So whenever we compare speeds, I think the most fascinating debate is not between Pepsi and Coke, but between Camaro and Mustang. Because, young people they always, they want to buy a car, a muscle car, waits for the better car which will go faster, which will get to a speed from 0 to 100 in the least time. You are talking about speeds, how much distance is covered in how much time; these are the important considerations in our minds.

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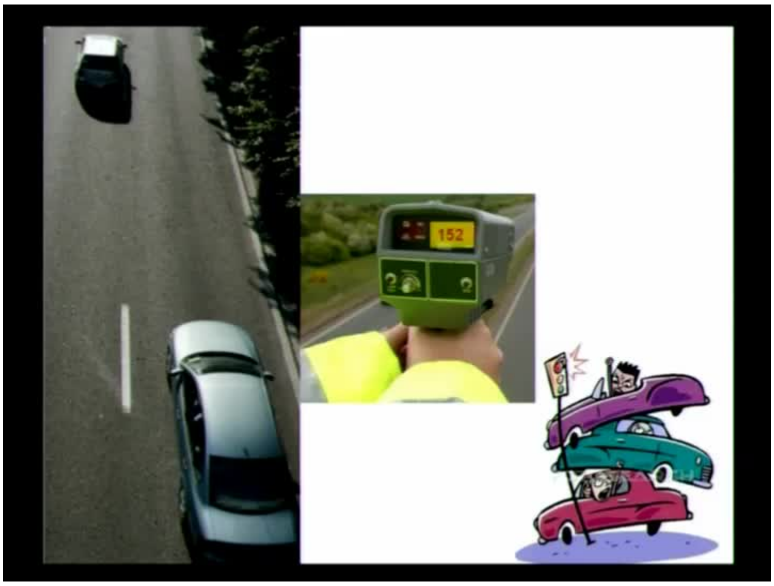

When we talk about speed, we need to measure it. Here, you have a speed gun; with this speed gun, let us say, you are measuring the speed of a car. Even if you are driving at a 152 kilometers per hour, you hope that you would not be caught, but that is a different matter. Here is a speed gun; a traffic officer records the speed of 152 kilometers per hour in a speed gun. He is looking at the speeds of two cars which are going on a road.

Now, the competition gets tough, this can have interesting consequences, but what is important is that if the vehicle is moving at a constant speed, if you have the vehicle which is moving at a constant speed, like a 152 kilometers per hour, maybe you use cruise control or something, then the car keeps going steady, the vehicle keeps going steady, there is no acceleration, there is no change of direction, but uniform speed with respect to the traffic officer. Then, we know from the Galileo that the state of motion at constant speed with constant momentum is completely equivalent to the mechanical state of rest that is Galileo's law of inertia, which gets incorporated in Newton's scheme as the first law of inertia.

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In other words, if you have, if you're watching a game Brett Lee versus Sachin Tendulkar, one of the most exciting competitions in cricket. You are watching this game; this game could be played just as well on the platform of a truck if it is large enough. As long as the truck is moving at a constant velocity, if the truck is moving at a constant velocity, there is no acceleration, the speed remains invariant, the direction remains invariant and you are not turning the vehicle. As long as there is no acceleration, this game could be played just as well on the platform of a truck, which is large enough let us say.

If you measure the speeds now, now let us ask the question who is measuring the speed, the speed of what? Here, we have Brett Lee bowling at a speed of 152 kilometers per hour. So, we are talking about these speeds in the framework of Galilean relativity. Here is speed gun, which is installed on the truck. This speedometer will record the speed of the ball to be at 152 kilometers an hour.

Suppose the truck itself is moving at 152 kilometers per hour in this direction, the speed is measured by a speedometer, which is mounted on the ground, then what is going to be the speed recorded over here, this speedometer of the ball that is bowled by Brett Lee. Yes, it will be 302.

Well, he is bowling backward; the truck is going forward, 0. If Tendulkar was to wait, he need to wait for hour, he keeps saying the ball was coming up to my bat that never would happen. But then, this observer who is not on the truck also sees the rest of the ground, the whole playground including the stamps, Tendulkar and everything moving up, his observations will be exactly the same as the observations of the observer on the truck. So, these ideas will become quite clear as we discuss this further, this is a nice truck with the usual messages on its tail.

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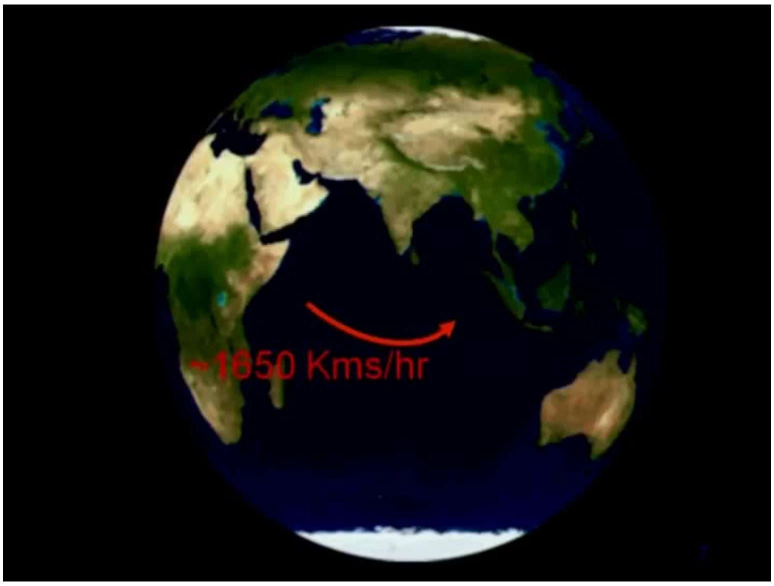

These speeds can be quite high, the tangential equatorial speed for example, this is like 1650 kilometers per hour, so one really has to take into account some of these effects. In addition to that the earth has got an orbital speed, the whole solar system is moving in the galaxy.

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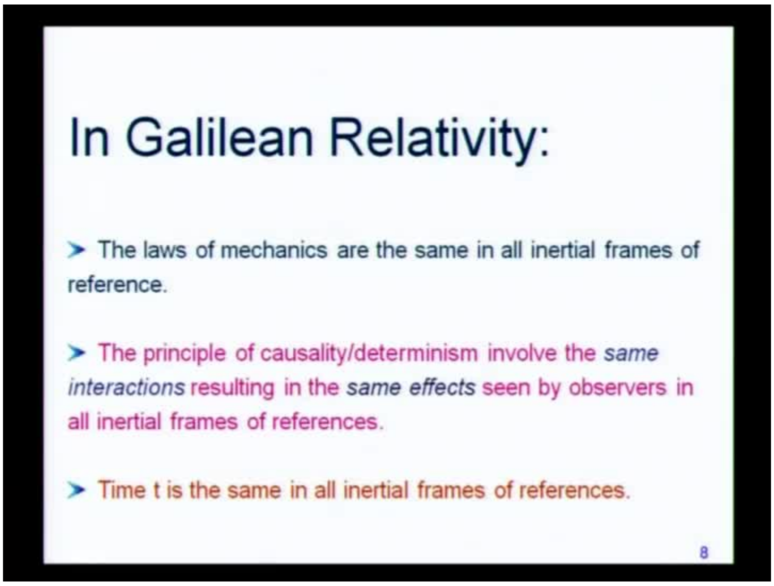

So, in Galilean relativity, the fact that the laws of mechanics are the same, whether they are observed by an observer on the truck or by an observer on the ground, as long as the relative velocity between them is the constant.

Which is really how you recognize an inertial frame of reference, this is the principle of inertia, which was identified by Galileo. The laws of mechanics are exactly the same in all inertial frames of references; this is the fundamental principle of Galilean relativity. Which essentially means, whatever principle of causality and determinism explain the dynamics, whenever equilibrium changed, in Newtonian mechanics we explain this by invoking a cause, generating a certain effect, which manifests as the change in momentum at a rate, which is d p by d t.

This cause effect relationship remains exactly the same for any two observers, who are moving with respect to each other at a constant velocity, such frames of references are the inertial frames of references. What is implicit in this treatment? Is that the notion of time is the same for all observers? This is something which we did not explicitly mention earlier, but it is implicitly understood.

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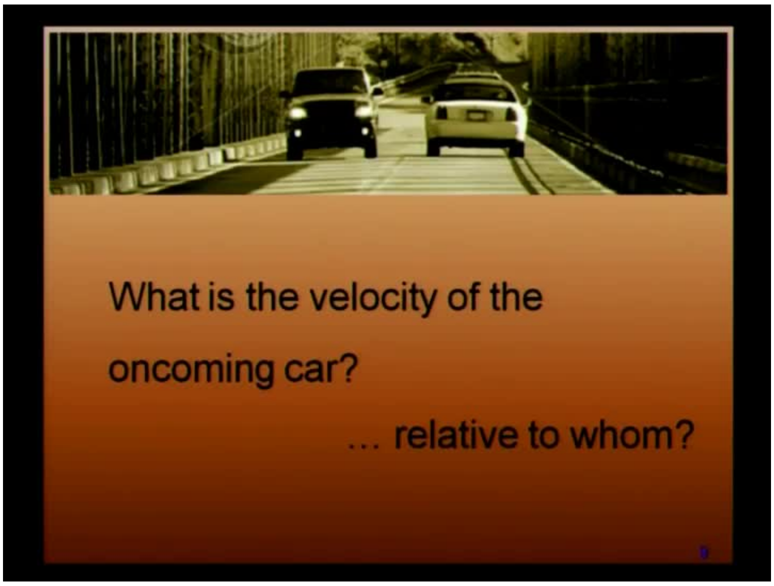

That the motion of time is exactly the same for both the observers, whether you are talking about the observer on the truck or the observer on the ground, regardless of which observer you are talking about, the notion of time is essentially the same in all inertial frames of references.

So, whenever we are talk about velocity, I will ask this question what is the velocity of an oncoming car? What is implicit in this question is always the idea of the observer who is talking about it, who is measuring it relative to whom.

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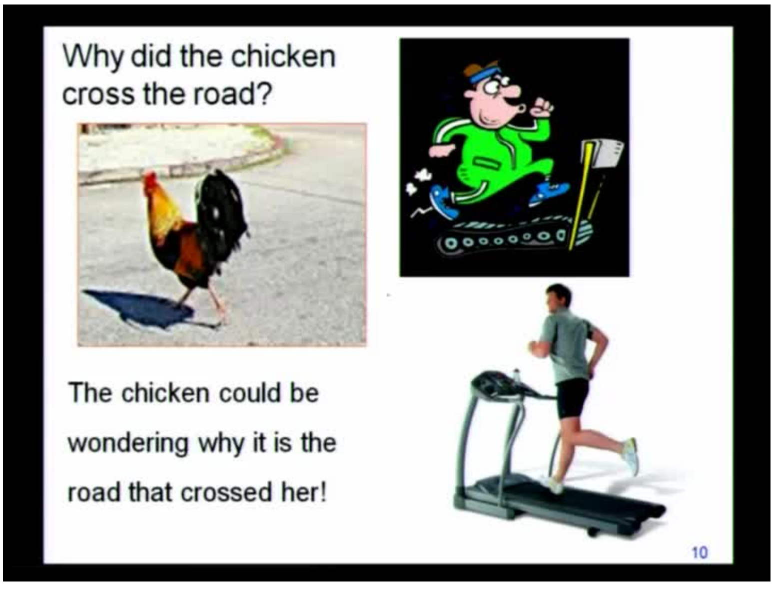

This is an important consideration; this is best stated in the famous chicken crossing the road jokes, which you might have read about. There are 1000 of answers on the internet, on why did the chicken cross the road, these are great jokes and the internet is flooded with these jokes. You will find several answers, one of which is this that the chicken could actually wonder why it is the road which is crossing her.

Because, who is crossing whom is a question of relativity. This principle really needs to be understood, we have to keep at the back of our minds these considerations that which observer are we talking about.

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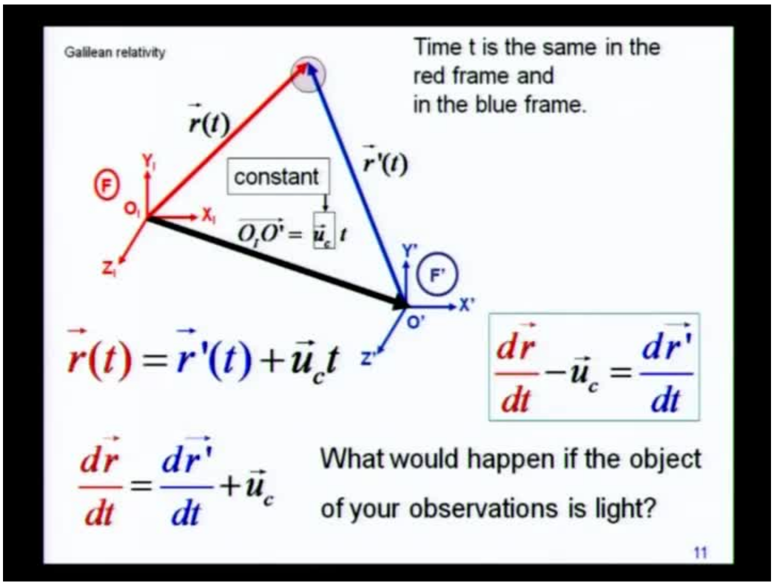

So, let us do it from first principles, we have got an inertial frame of reference, this is the red frame of reference, this is an inertial frame of reference, so the subscripts are I for inertial. This is the origin and then you have got an X Y and Z axis. Related to this frame of reference, we now consider another frame of reference, which is moving at a constant velocity u subscript c, c for constant.

This frame of reference moves at a constant velocity with respect to this. In other words, both are inertial frames of references. The displacement vector between them is obviously this velocity time, so this is the relative difference between the origin O prime and O I, if the two frames coincided when you start your time clock.

Now, let us say that an observer in this frame of reference looks at a certain object. In his frame of reference, the position vector of this object is r, at the instant t, which will - this object could be in motion, it could change from time to time. So, I write it as a function of t. What is the position vector of the same object for the other observer? It is r prime of t. You will know from the triangle law of addition that this red vector is the sum of this black vector plus this blue vector.

So that is simple enough, this black vector is the displacement vector, which is u c times t. Now, if you take the time differential of this vector d r by dt, then you get d r by dt equal to the rate of change with respect to time of this; the derivative of this term gives you this constant. If you flip this equation for the velocity measured by the second observer in this blue frame, the velocity of the same object measured by an observer in this is not equal to the velocity measured by the first observer, but he must subtract his own velocity with respect to the other observer. Now, this is common experience. Now, what would happen if, what they are looking at is not just a cricket ball or a truck or a car, but what they are looking at is a light?

The object over here, this purple thing, this is what both the observers are observing. It is a velocity of this object that these two observers are measuring, we are asking the question will their observations be consistent with this expression over here, if what they are looking at is not just a truck or a car or a plane, but it is light itself? Does this relation still hold?

It turns out that this is where the finiteness of the speed of light plays a big role; we will see why that happens and how this is to be addressed.

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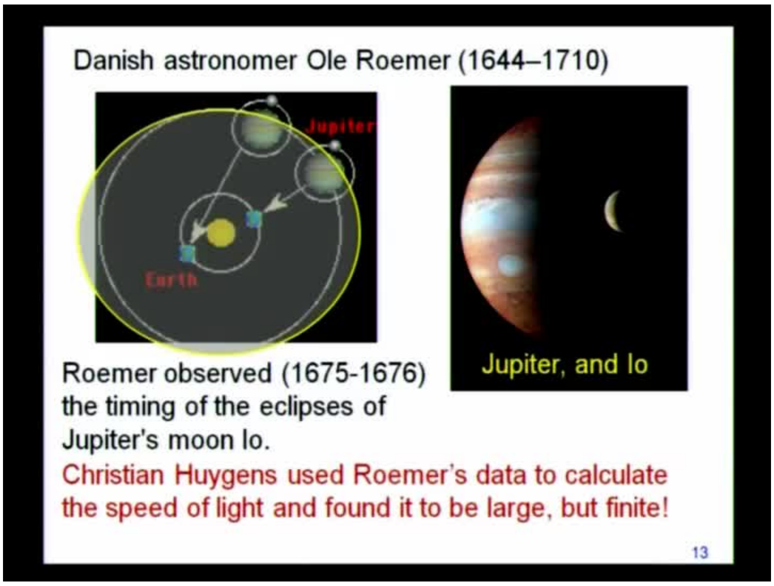

Now, speed of light, it is our normal expectation of the speed of light from our common experience, common intuitive expectation of the speed of light is almost that it is like instantaneous, the movement you light a candle. You see the light and you get a feeling that light takes no time at all to travel from the source to the observer. That is equivalent to saying that the speed of light is infinite now. There is no point in making guesses, one need to make observations, measure it, so you need to have good measurement device, some noise experiment that you can set up, so that you can measure the speed of light. You can have some identification of how much time light takes to travel from source to the observer.

So, the first good experiment on the speed of light was made by this Danish astronomer, Ole Roemer. What he did was to observe that the one of the moons of Jupiter. Jupiter has several moons; Io is one of the well known moons. What he did is that when this moon, this Jupiter's moon as it goes and circles Jupiter, when it goes behind Jupiter, it gets eclipsed, right. So, it will not be seen from the earth, there is a certain time interval which must lapse between the time at which you sight the moon on one side of the Jupiter, when you sight it on the other.

You record the timing of the eclipses of Jupiter's moon, so these are the observations which Roemer carried out in 1675, 1676. There about these were the first fairly accurate measurements of the speed of light. What he did was to perform these measurements also when Jupiter was at a different part of the sky. If you remind yourself that the orbit is slightly elliptic, then the time that elapses between these eclipses of Io, would be slightly different, when Jupiter is in a different part of the sky.

Form these differences, one can arrive and one can get an estimate of speed of light. So, this is the technique, which Roemer carried out, in fact he only noted the observations, the calculations were actually done by Christian Huygens. He used Roemer's data to calculate the speed of light, he found that it is finite, it is very large. He got an answer, which is not too far from the presently known value for the speed of light, I have not recorded it over here, but you can find that in literature easily, which Roamer's measurements is. I got an answer which was fairly good, very high, but finite.

This was the first observation of the finiteness of the speed of light that is not infinity. No matter how fast light propagates in space, it does not propagate at infinite speed; there is a finite speed of light.

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The better known measurements are of Michelson and Morley, what they concluded is what they had hope to disproof that the speed of light is different for different observers, but they ended up proving that it is the same in all inertial frames of references, but I will not go into that history. But, they reported this in 1887 in American journal of science. Here is a picture of the experiment, which they set up. What they had done was to use spectroscopic techniques; they mounted their apparatus on a solid stone block, which was floated on a pool of mercury.

Because, mercury is very denser, it could support stone. Then, they could actually rotate the stone through 90 degrees. The idea was to measure the velocity of light in two transverse directions. They found that it turns out to be the same, essentially the conclusion was, I will not go into the history of this experiment or the details of this experiment, but focus on the conclusion of this experiment that light travels at constant speed in all inertial frames of references. Now, this was the main conclusion that we have to come to terms with.

Which is really shocking if you have the earlier equation in your mind, d r by dt is equal to d r prime by dt plus or minus, you see it right. So, there was a constant term had to be added or subtracted. So, the observer had to take away his own velocity with respect to another inertial frame of reference, to get the correct velocity of an object, you cannot do with light.

This was a very shocking result. Here, at the bottom of the slide, I gave the correct value of the speed of light, this is what is approved by the codata, this is - these are the standard values. It is not just three, there is of course, you know 2.99792 etcetera 10 to the 8 meters per second. This is the currently accepted value of the speed of light. Those of you who are interested in the history of this may visit this website of the American institute of physics. In which, it is also pointed out that it is perhaps not in the Michelson Morley experiment itself, which was the main motivation for the development of Einstein's theory of relativity. Although it may have played some role, but it is not obvious that it was the main consideration, because there were many other things going on in physics.

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In particular, I want to draw your attention to what was this is known at that time in the subject of electrodynamics. The Coulomb's law was known, Amperes law was known, Gauss's law was known and Faraday's law was known. I am not going to go through this, but just draw your attention to this. I presumed that you have either studied these things in some other subjects, in some other classes or else a little bit of introduction to some of these things we will have also in later part of this course.

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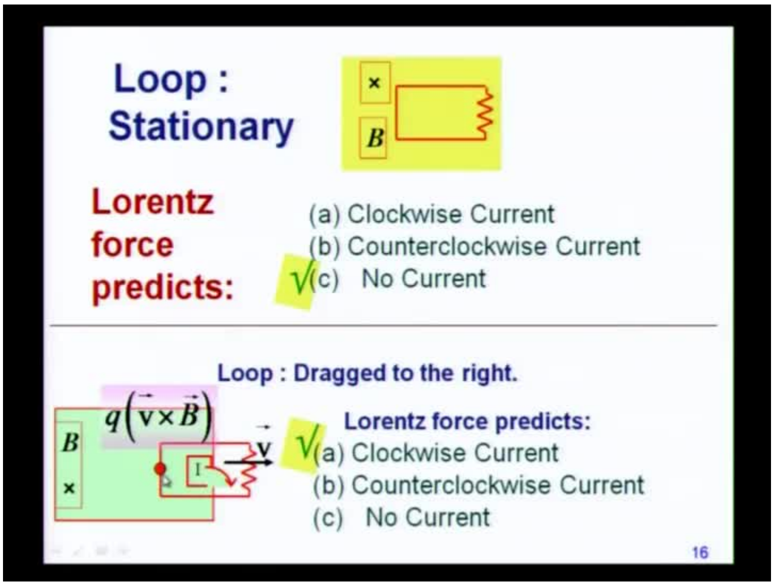

Let me bring out a very fascinating aspect of these experiments, which come from the application of all this put together, the Coulomb’s Law, the Gauss’s Law, Faraday’s Law, Ampere’s Law and Faraday Lenz’s law, everything put together. You do this experiments, suppose you have got a certain region of space, in this region of space, you have got a magnetic field B, this is a vector.

I choose a vector field B, which is pointed into the plane of the screen that you are looking at, so if this was represented by an arrow, you would see the tail of the arrow. You have got is a circuit, this loop - this is an electrical loop, it is stationary. This is the experimental set up, the question we ask is will there be a current in this loop. If there is a current, would it be clockwise as you are looking at it or would it be anti-clock wise or will there be no current at all. The answer to this question of course is that there will be no current.

You just have got a magnetic field or you have a static loop, there is no reason to find a current in a term. Now what you do in your next experiment, you drag the circuit to the right, at a certain velocity. You have got the same set, up you have got the same magnetic field, in the region of the magnetic field, you have this circuit or you drag it to the right.

Now, will there be a current in the loop? Yes. Because, if you over to think of a positive charge over here, this would seem to be drag to the right, so it would experience a lorentz force, which will accelerated in this direction and set up a current which will be clockwise. In real circuits, it is not the positive charge which moves, but the negative charge which moves in the opposite direction, is the different story. That is the minor thing that is another relativity, but no big deal about it that is just about the sign of the charge, so that is not an issue here.

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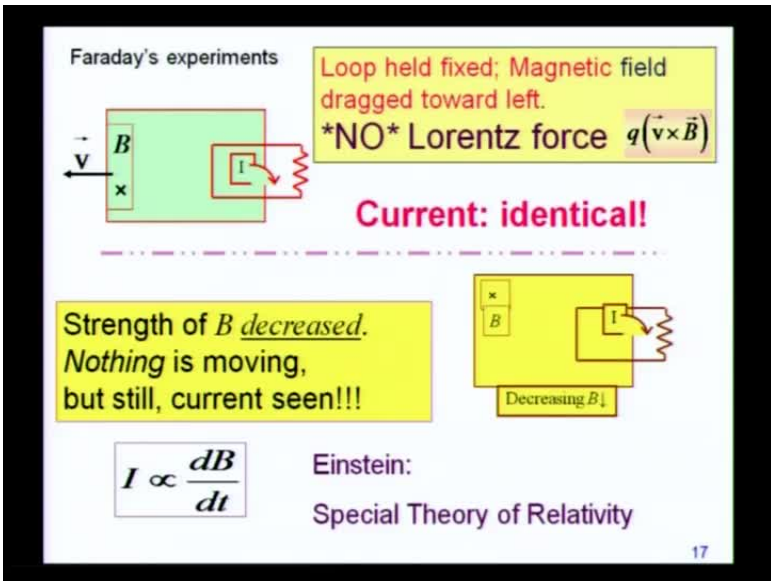

So, we know that there will be a current; there will be a clockwise current. Now, what we do is, we do the same experiment, we keep the loop static, we do not drag the loop to the right, but instead we drag the magnetic field to the left. The magnetic field could be generated by a horseshoe magnet or something and you move that magnet.

So, you move the magnetic field itself to the left. Now, if you have to ask this question q into v cross B this, v is the velocity of the charge particle, which is the particle of the loop. Now that loop itself is static, you are not moving it. So, you cannot think of any force in terms of the v cross B, right. The q v cross B term in this case cannot be invoked, because this charge is at rest, you are not moving it. In your frame, it is not moving at all, but the result is the same that there is an identical current.

Furthermore, if you do this experiment in which you move neither this loop - the electrical circuit, nor the magnetic field, you do not change anything, but just decrease the strength of the magnetic field. Just change the magnitude of the magnetic field, even then you find that there is a current. Now, this is an incredible result, more than anything else, perhaps more than Michelson Morley experiment. It seems that it is this experiment, which pumped at Einstein to come up with the theory of relativity. Reinterpret notions of space, time and the finiteness of the speed of light, everything else that would follow.

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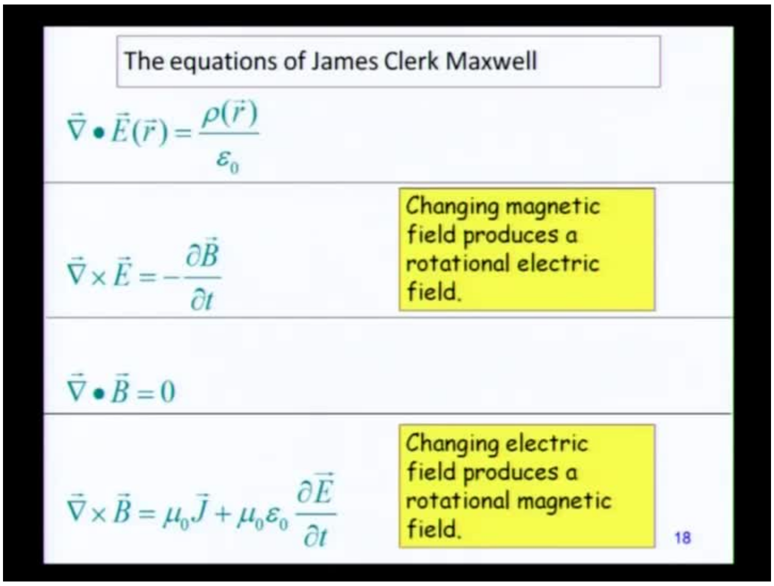

Now, all laws of electrodynamics are contained together, they can be packed together in Maxwell's equations. You can do a little bit of vector calculus with this, these are well known relations. You can do a little bit of further calculus with this; arrive at the so called wave equations.

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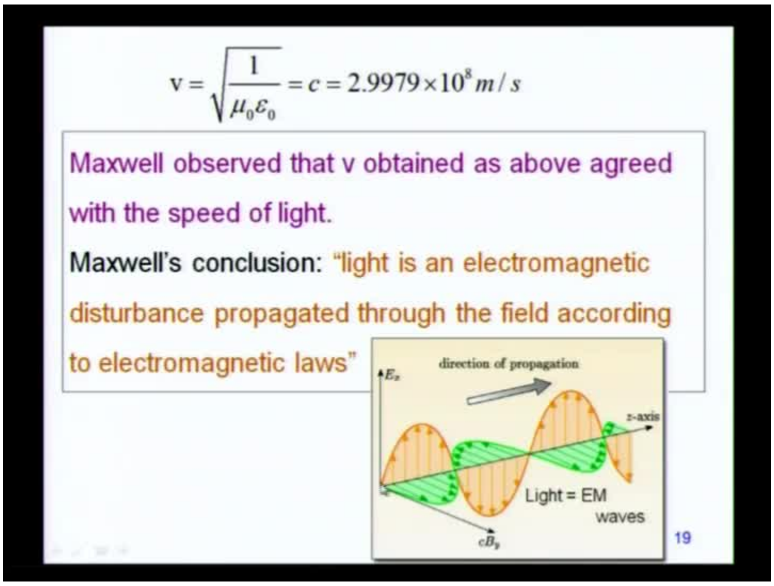

What these wave equations tell us is that the electromagnetic field propagates at a certain speed, which is given by the square root of 1 over mu 0 epsilon 0. This is the magnetic permeability of free space, this is the electric permittivity of free space and this gives the speed at which the electromagnetic waves travel in space; this comes straight out of Maxwell's theory.

What Maxwell observed is that the speed that comes out of this calculation is exactly the speed of light? This is the speed of electromagnetic wave, which turns out to be exactly equal to the speed of light. Therefore, Maxwell concluded that electromagnetic waves and light are the same physical phenomena, this was his conclusion. You have the electromagnetic field, the electric vector and the magnetic vector orthogonal to each other, the disturbance itself propagates in a direction, which is orthogonal to both of them, in the direction of E cross B that is the pointing vector. Now, this was known at Einstein's time, as well as the Faraday Lenz experiments.

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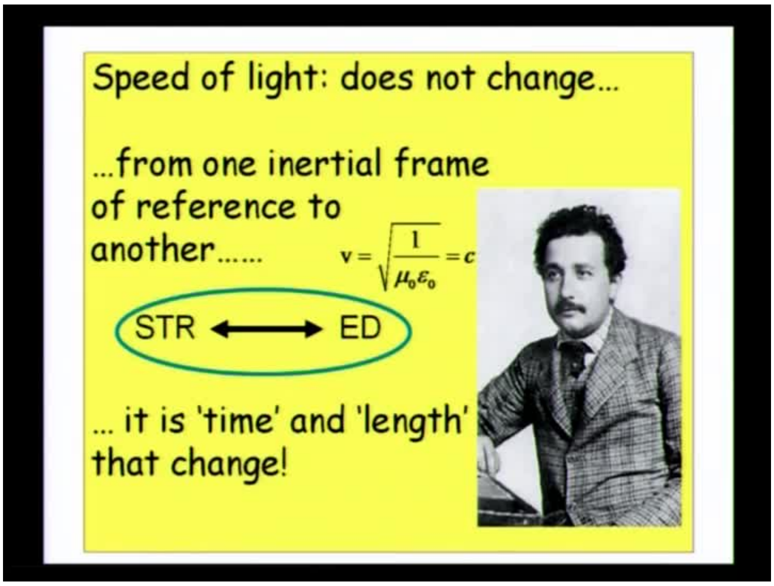

Now, what is interesting is that the speed of light turns out to be given by properties of vacuum mu 0 and epsilon 0. No way did we talk about who is measuring it, in which inertial frame is it, therefore the speed of light must be the same in all inertial frames of references. Because, the Maxwell's equations are correct in inertial frames of references, the speed of light is determined only by properties of vacuum. Therefore, the speed of light must be the same in all inertial frames of references, even if they are moving with respect to each other at a constant velocity.

Now, this is the conclusion that Einstein arrived at. If this speed is to be the same, then we have to worry about what is speed. Speed is after all the ratio of distance over time. If speed is the same, may be what constitutes this ratio, distance over time, distance in the numerator and time in the denominator. Distance over time giving the speed, speed being the same, may be this distance and time adjusts in some strange way, which we had not known before. That would explain the constancy of the speed of light in every inertial frames of reference, this was Einstein's reasoning.

What you see is that the special theory relativity and the theory of electrodynamics are intimately related. They are intimately connected, there is a fundamental connection between the two and this is what the special theory of relativity is about.

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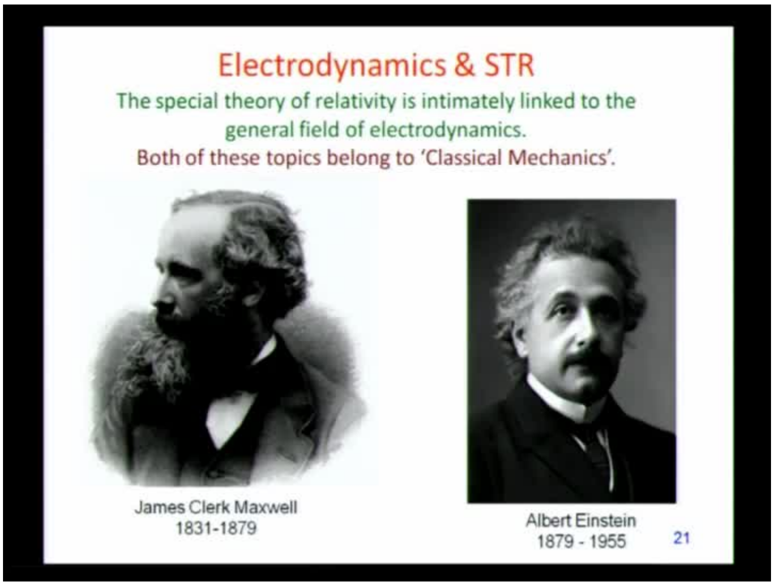

Both of these topics electrodynamics and the special theory of relativity belong to the framework of classical mechanics, which is why an interaction to both of these topics is included in this course. They are absolutely intimately related to each other, electrodynamics contained in Maxwell's theory and special theory of relativity formulated by Albert Einstein.

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We will now see how our understanding of how transformations are to be carried out from one frame of reference to another. We had done this all along using Galileo's laws of transformation. How velocity and accelerations in one frame of reference are related to that in any other. Whenever we discuss this topic earlier, in our earlier discussions in this course, we made use of Galilean relativity, in which time was considered to be the same in all inertial frames of references. We will have to refine these considerations; Galileo's laws of transformation will have to be replaced by Lorentz transformations, so we will introduce ourselves to Lorentz transformations.

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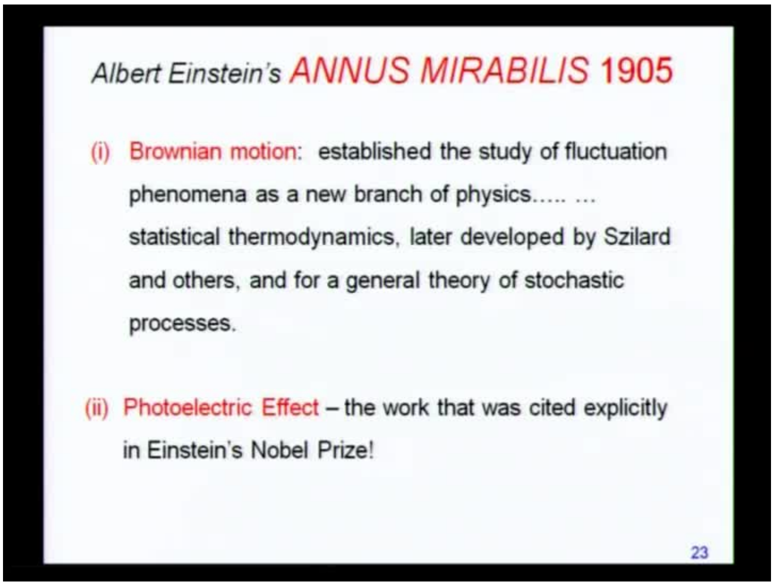

Now, all these happened in the year 1905, which is famously described as Einstein's miracle year. It really was a miracle year, because Einstein did so much in that one single year, it is amazing to understand how a human mind could be as productive in such shorten interval of time as Einstein's was in the year 1905. I do not know of any other period in the history of mankind, that there has been so much of an intellectual burst in a small period of time in one year. What Einstein did in this year was to explain the Brownian motion; this became the framework of understanding of stochastic processes.

Einstein had a very famous paper on this, same year Einstein explained the photoelectric effect, which was observed in the experiments of Hertz and Lenard. This is a work for which Einstein eventually got the noble prize, this means of course the Einstein had contributed lot, but his interpretation of photoelectric effect is the one that was explicitly mentioned in the citation for his noble prize.

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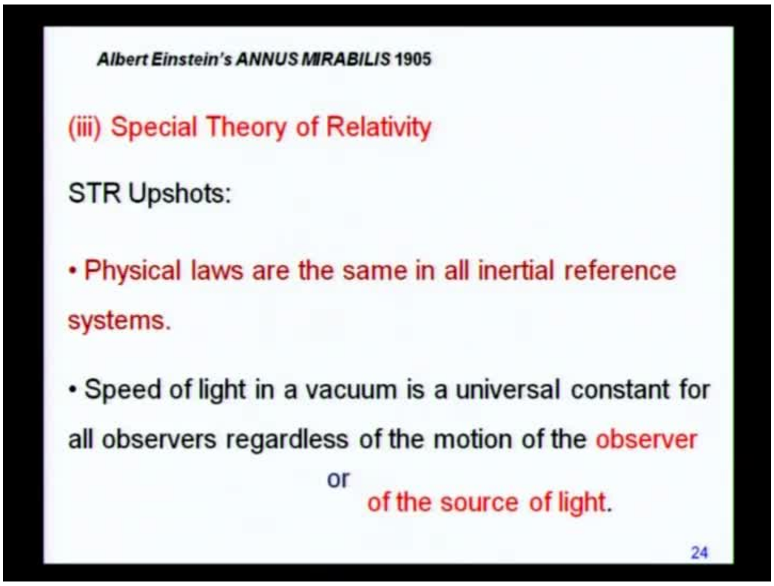

Then of course he came up with the theory of relativity. These are the consequences, which are called as STR upshots, STR a special theory of relativity. Physical laws are the same in all inertial reference systems. Now, this point by itself was not completely new at Einstein's time, because we had it even within the framework of Galileo and Newtonian mechanics, but it was tested only for motion of mechanical objects, means of course at Galileo's and Newton's time there was no electricity was understood.

Coulomb's law and Maxwell's equations all of these came later, so at the time of Galileo and Newton, electrodynamic events were not analyzed. So, this conclusions that physical laws are the same in all inertial reference frame, which is this particular statement, provides the framework of Galilean relativity, gets incorporated in Einstein's theory of relativity as well with the difference that it not becomes applicable, not only to the mechanics of particles as was done at the time of Galileo and Newton, but also to electromagnetic phenomena including light.

Light is electromagnetic wave, as we have already reconciled with. Second, the speed of light in vacuum is a universal constant; this is the fundamental reality, the fundamental stipulation which became a part of the essential framework on which the theory of relativity is built. That it does not depend on the state of motion of the observer or of the source of light. Even if the source of light is moving, it would not matter.

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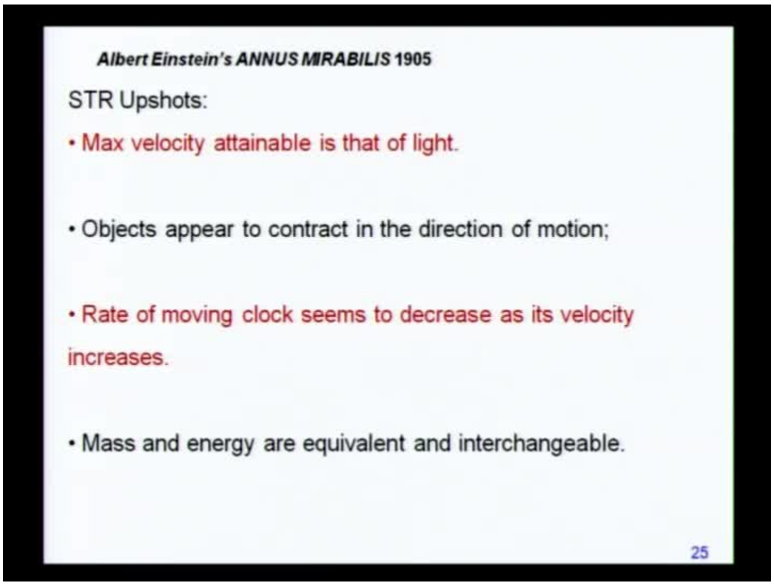

These are the some of the important upshots of the special theory of relativity. There are other consequences, the maximum velocity or anything, any object can take is that of the speed of light, it cannot. There is a light barrier as it is called, you cannot cross that barrier. Then there are, rather you know very unusual consequences that we had not imagined in the pre Einstein era, these are the contraction of the length scale. The objects appear to contract in the direction of motion that the rate of moving clock seems to decrease, as its velocity increases, so this is called as time dilation.

These are completely new ideas, new from the point of view Galilean relativity. These are some of the consequences that came out; we will see why this happens. There are other consequences which lead to the equivalence between mass and energy, they are also interchangeable or there are several other consequences, I will mention some of them.

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Why is this important for us? If for no reason, at least for the fact that any Tom Dick or Harry, two monkeys, they talk to each other on cell phones these days. So, let us not move in a world, in which we think that the theory of relativity is of no relevance to our lives, it affects our lives directly. Because, even this cell phones work the way they do, because the theory of relativity is correct. If you have to use laws of physics and electronics without reference to the theory of relativity, you will not be able to come up with devices such as the cell phones.

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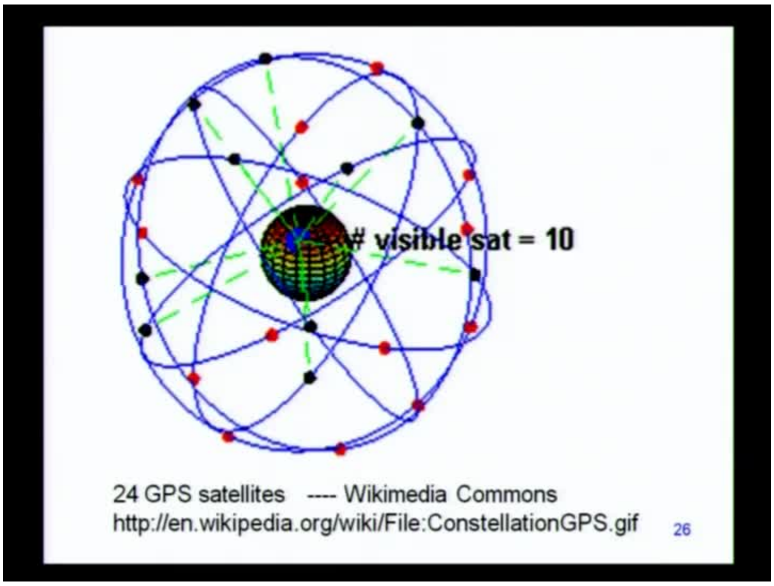

Now, let us see why this happens? This is how the cell phones work. Fundamental principle that is employed is the global positioning system, right the GPS. You are carrying it in your pockets; they have these receivers, which get the signal from the satellites. There are about 24 GPS satellites, these GPS satellites, there should be some certain minimum number of satellites, which can connect to the receiver.

You are throwing some triangulation and so on, then you can position where the receiver is. You must take into account the speeds at which the satellites are moving, these speeds are not the satellites, since they are moving relative to you. What is length and time for you is not the same as length and time on the satellite, but there is another reason for it, which actually comes from the general theory of relativity, but I will comment on that a little later. It turns out that the theory of relativity is absolutely important, if you did not take account of these things, then the GPS system will not work.

This is one of the very many reasons, why not only scientists, but engineers, electronics engineers, communication engineers, those are who produce these devices using dielectric materials and so on. So, material scientists, chemists, they all need to have some understanding, some interaction to what the theory of relativity is about.

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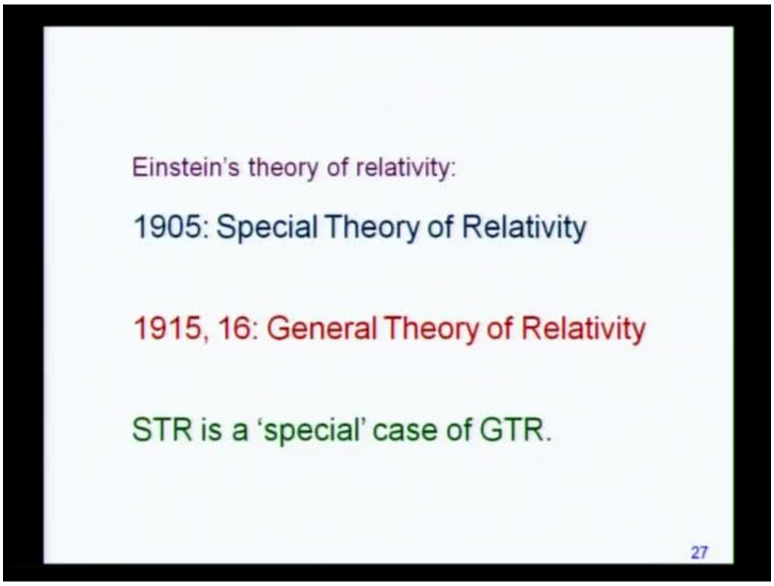

This is what is called as the special theory of relativity. Relativity because, you compare observations by two observers, who are in motion relative to each other. There is a relativity, special because it turns out to be the special case of another theory, which Einstein formulated later, which was at 1915 16 to at the end of 1915 actually, which is known as the general theory of relativity. Which is actually well beyond the scope of this course, but I will make a few comments about it.

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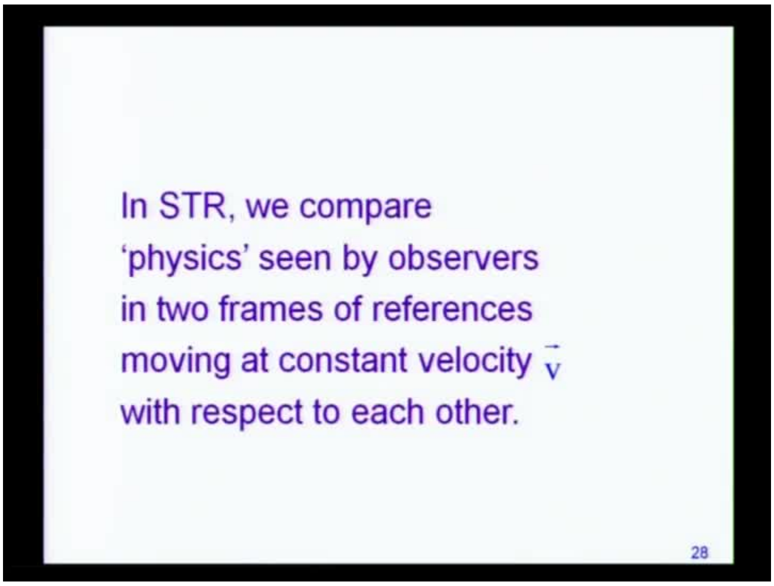

So, essentially we are going to focus on how we interpret the physics that is seen by two observers, who are in motion with respect to each other at a constant velocity. So, both the frames of references are essentially inertial frames of references, this will be our topic of discussion.

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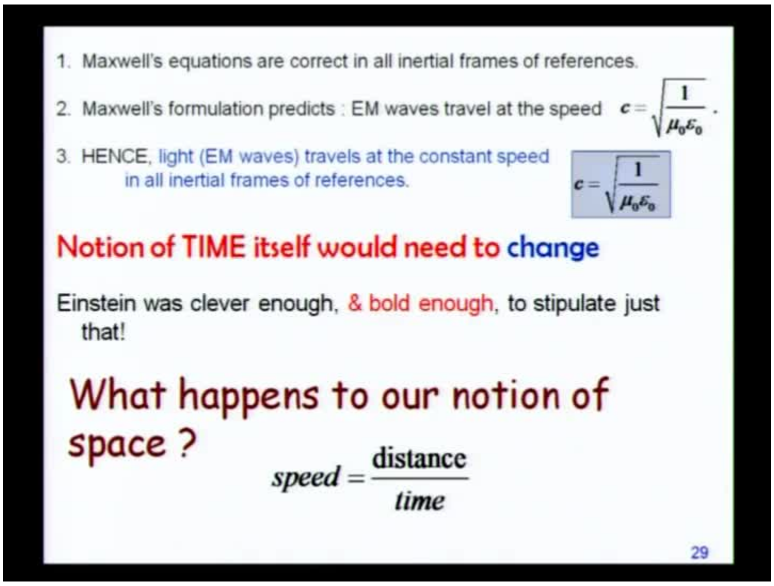

Our main conclusions are the following; Maxwell's equations are correct in all inertial frames of references, no dispute there. Maxwell's formulations predict that the electromagnetic waves and light propagates at a speed determined by properties of vacuum, no dispute there. Now, if you put 1 and 2 together, do in your minds quickly, you must conclude that the speed of light is the same in all inertial frames of references.

Whether you like it or not, you cannot escape the consequence contained in statement number 3, if you have come to terms with statement number 1 and 2, you cannot escape. What this so forces to do is that we must change our notion of time. Einstein was smart enough to do that he was courageous enough to do that because it is a very bold idea, exceptionally bold idea. Einstein stipulated just that. Then our notion of space must also change, because after all speed is distance divided by time. If speed of light has to be same in all inertial frames of references, then somehow distance and time these two must adjust to each other in such a way that the ratio that they generate for light turns out to be the same in every inertial frame of reference. This will become very clear when we discuss the twin paradox.

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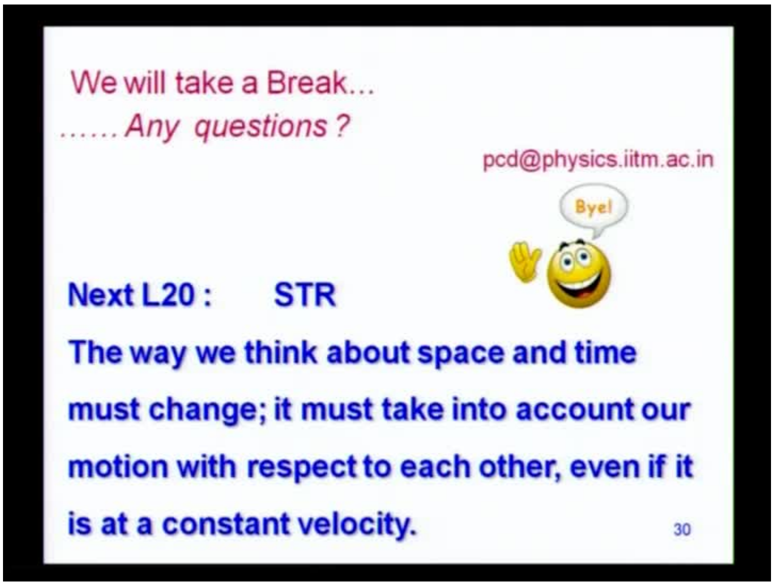

So, at this point we will take a break, I will be happy to take some questions. It is a length contraction and time dilation occurs simultaneously or is they two different phenomenons, sir? Both are automatic and essential consequences of just one fact. The speed of light is the same in every inertial frame of references. Length contraction is not a new postulate, no ways time dilation a new postulate. There is just one fundamental reality that the speed of light is the same in every inertial frame of reference.

If you accept this, you cannot escape from this. The moment you accept it, you cannot escape from the consequences. The consequences are very many 1, 2, 3, 4, 5, 6; let me mention the third and the fourth consequence before I come to the first and second. So, there are number of consequences of this, you have to accept all these consequences. One of the consequences is that the electron must have intrinsic spin, another consequences is that mass energy are equivalent - inter convertible, you cannot escape from any of these consequences.

The consequence number 1 and 2, we are directly talking about is length contraction and time dilation. You have to accept all these consequences together, it comes as a package. So it is not that one leads to the other, it is not that consequence a leads to consequence b leads to consequence c, it comes as a package; is it clear, any other question?