Select / Special Topics in Classical Mechanics

Prof. P. C. Deshmukh

Department of Physics

Indian Institute of Technology, Madras

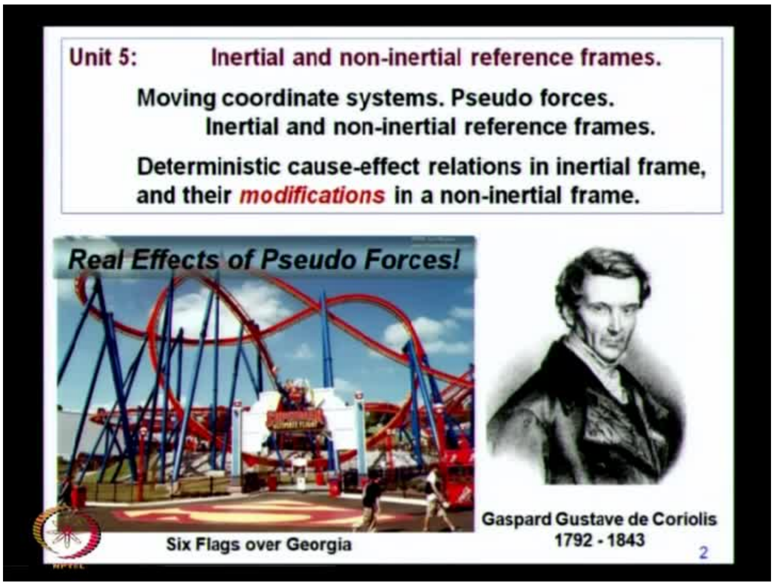
Module No. # 05

Lecture No. # 15

Real Effects of Pseudo-Forces

Greetings, we will begin with unit 5 in today's class. This is an interesting topic, because we will be talking about pseudo forces. The word pseudo suggest that there is something unreal about it and then we will see they generate real effects. So that is part of the reason that some of my students and I, when we were talking about it, we decided that we will call this as a real effects of pseudo forces.

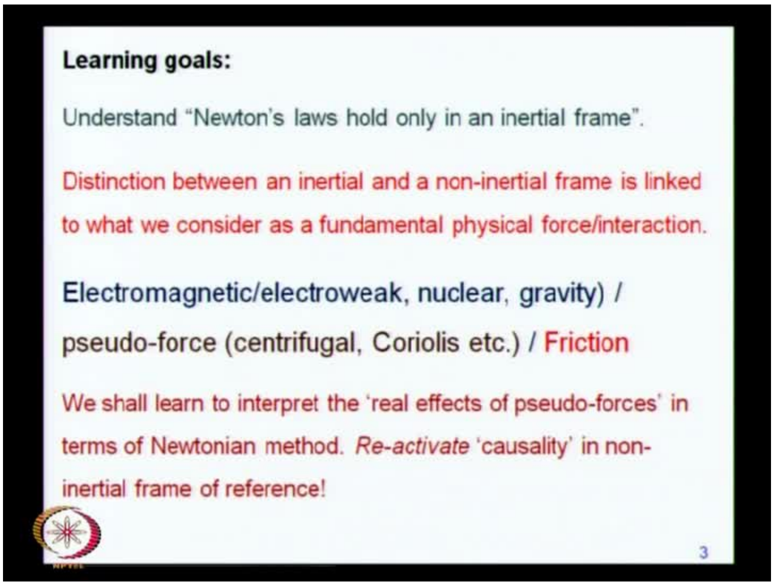
(Refer Slide Time: 00:50)



We will learn about moving coordinate systems. In particular, our focus will be on understanding what is meant by an inertial frame of reference as a force to non-inertial frame of reference.

We will spend some time as simulating our understanding of the deterministic cause effect relationship, in an inertial frame of reference and how this idea can be modified in non-inertial frames. We have the important contributions due to Gaspard Coriolis.

(Refer Slide Time: 01:33)



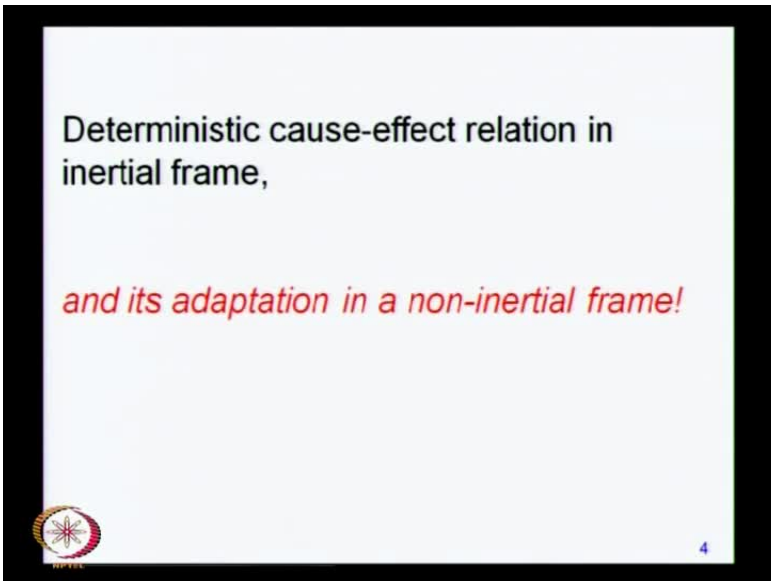
It is always said that Newton's laws hold only in an inertial frame of reference, we need to understand exactly what this means. The reason this is so important is, despite the fact that there is early introduction to this idea in these schools, even in 7th or 8th grade school education, one learns about Newton's laws, one learns statements of this kind that Newton's laws hold in an inertial frame of reference. This course, which is designed for first year students, after the high school, in college, I like to spend some time discussing this idea further.

The reason is this idea is extremely fundamental, what it will tell us is, what we call is the force or in modern language, what we call as an interaction. Mean, this idea of a fundamental interaction, what is the fundamental interaction at all? That is what physics is about, physics is about exploring fundamental laws of nature.

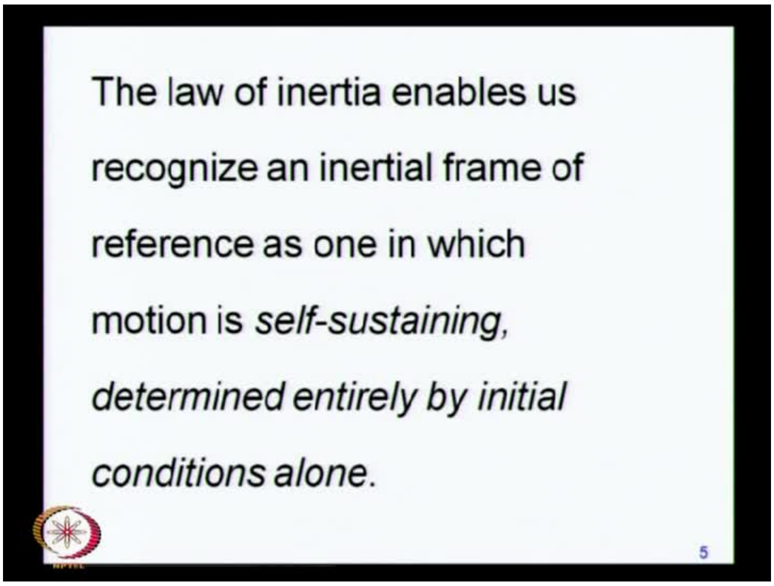
What is the fundamental interaction is something that we really need to understand. This understanding is incomplete without a very deep understanding of Newton's laws. In particular remarks of this kind that Newton's laws hold only in an inertial frame of reference.

The fundamental forces that we understand and width that we make use of in modern physics or electromagnetic forces, electroweak forces, nuclear strong or nuclear weak interaction or the electroweak interaction, if you talk about the unification between the nuclear weak interaction and the electromagnetic interaction, then there is gravity, which six's out, which continues to pose major challenge. Then, we also make use of pseudo forces, which are not fundamental forces, but then their forces nevertheless. There are other forces that we talk about like friction and so on. We really need a very clear understanding of the differences between these, because most often we do work in non-inertial frames of references and yet we see causality. If causality is to be reactivated in frames of references, which are not inertial frame of references, then how, what we do it? These are certain question, nevertheless very settle, which is why they do seek if further discussion. So, these are some of the ideas that we shall be discussing in this unit.

(Refer Slide Time: 04:51)



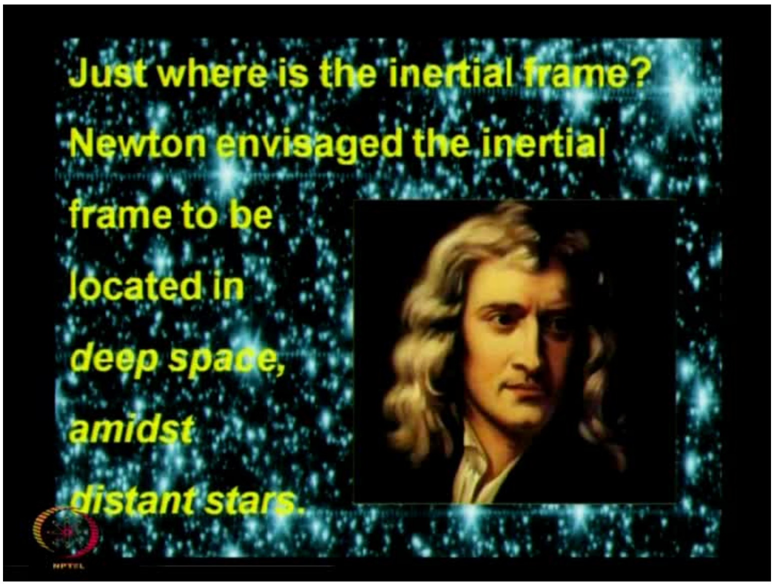
(Refer Slide Time: 04:59)



Now, what is it that we regard as an inertial frame of reference, how do we define an inertial frame of reference? Very often, the text book definition in these schools is not very useful in this particular situation, because in a text book, inertial frame of reference is often defined as one in which Newton's laws hold or else, it is defined as one which moves with respect to another inertial frame of reference at a constant velocity. Neither of these two definitions seem to help very much, if you really ask what is it that these definitions really mean? What we have to admit as a starting point is the Galileo's interpretation of inertia. That motion is self-sustaining in an inertial frame of reference, if it is determined completely by initial conditions.

Initial conditions alone determine the motion completely. Now, if this is what happens in a frame of reference that you are in, then you could conclude that you are in an inertial frame of reference. So, the essential criterion that I would like to highlight is that in this frame of reference, motion is determined entirely by initial conditions alone.

(Refer Slide Time: 06:53)

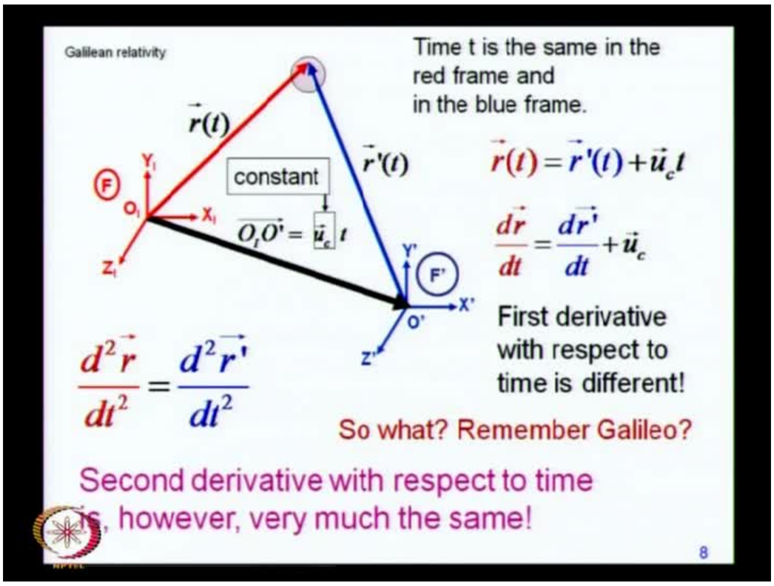


This is particularly useful as a pose to some of the other criteria, which are invoked to reference what an inertial frame of references or to point out what an inertial frame of references is? This question of course was important for Galileo, it was important for Newton. The early idea that Newton envisaged was that in an inertial frame of reference is situated in deep space, amidst distant stars.

(Refer Slide Time: 07:59)

Now, this is in a certain sense a very romantic idea, it is almost poetry. That the inertial frame of references situated in deep space, then to a greats Newton's romance, it sort of distance on earth and it reminds me of this song from the movie [fl] in which, he says that [fl]. It is like a frame of reference, it is situated deep amidst stars and then it distance on earth just to address Newton's needs or Galileo's needs to have an inertial frame of reference, but there is move to this than just poetry in romance and that is what we need to talk about.

(Refer Slide Time: 08:35)



We have agreed that we will recognize an inertial frame of reference as one in which motion, the evolution of a system, the temporal evolution and the time evolution of the mechanical straight of a system is completely determined by initial conditions. Let us consider this red frame of reference, this is a Cartesian frame of reference X, Y and Z and this carries a subscript I to tell us that this is the frame of reference that we will regard as the inertial frame of reference.

Let us now talk about another frame of reference, whose origin, O prime moves with respect to the origin of this inertial frame of reference, which is O I and this moves at a constant velocity. So, the displacement vector between the two origins is equal to this u t, where u or u subscript c is the constant velocity of the frame F prime with respect to F.

Now, how will these two observers; the observer in the red frame which we have identified as an inertial frame of reference as one, in which motion is determined entirely by initial conditions.

How do the observations of an observer in the inertial frame, which is the red frame, which is the frame F compared with the observations made by another observer in the frame F prime? The observer look certain object, whose position vector in his frame of reference is r t and this object has got at different position vector, which is r prime in the frame F prime.

You can use this triangle law of addition, you know that these two vectors are r prime and related to each other through this displacement vector O O prime, which is u c times the time that has elapsed. Since, the frame of reference F prime crosses the point O I, so that is the model we have in mind.

Now, for simplicity, we assume that the frames of references have their coordinate accesses, which are mutually parallel to each other. So that the X prime is along X, Y prime is along Y and so on, but the only thing is that at, what we will call as time 0, which is the reference time, from which we start observing the system evolution. O prime get separated from O I and it starts moving at a constant velocity u c, so that is our conjecture.

If you differentiate this with respect to time, this is within the realm of what we call as Galilean relativity. In Galilean relativity, this time has got an absolute significance in both the frames of references; you do not need to modify the perception of time in the blue frame as it is in the red frame. This is anticipation or what we shall discuss in the next unit, which is unit 6, in which we will discuss the special theory of relativity. In which we will make use of the Lorentz transformations, in which time itself needs to be modified as you go to another frame of reference.

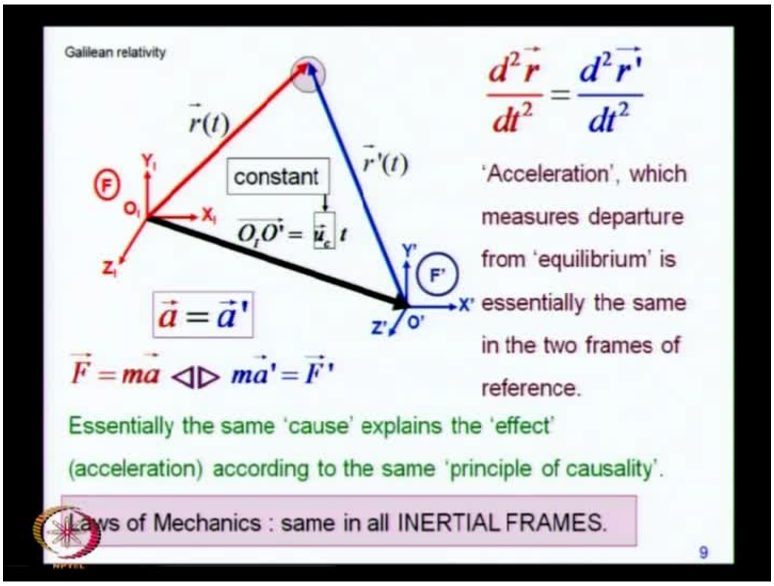
So that idea is not involved over here, this is the pre-relativistic transformation; this is what we call as the Galilean transformation. In this, time is same for both the observers; you take the derivative with respect to time to get the corresponding velocities, you get a relationship between the velocities as will be observed by an observer in the frame F. Compare it with the velocity of the same object as the scene by the observer in the frame F prime.

Now, obviously, you see that the first derivative is different; the two velocities are different and the differences by this constant velocity u, this comes from a simple differentiation with respect to time.

The velocity is a different, but what is a big deal? If the velocity is a different, it does not change the perception of equilibrium in the two frames of references, because we already learnt from Galileo's law of inertia that the state of rest and of uniform motion are completely equivalent to each other and these do not require any calls. In these states, motion is determined completely by initial conditions, a cause will be required only when equilibrium is disturbed. The detection of the change in equilibrium will be in terms of the second derivative of the position like, not the first.

The first derivative is what gives you the velocity. If the two velocities are different, no big deal about it, but to see if there is any departure from equilibrium, we must look at the second derivative.

(Refer Slide Time: 15:20)



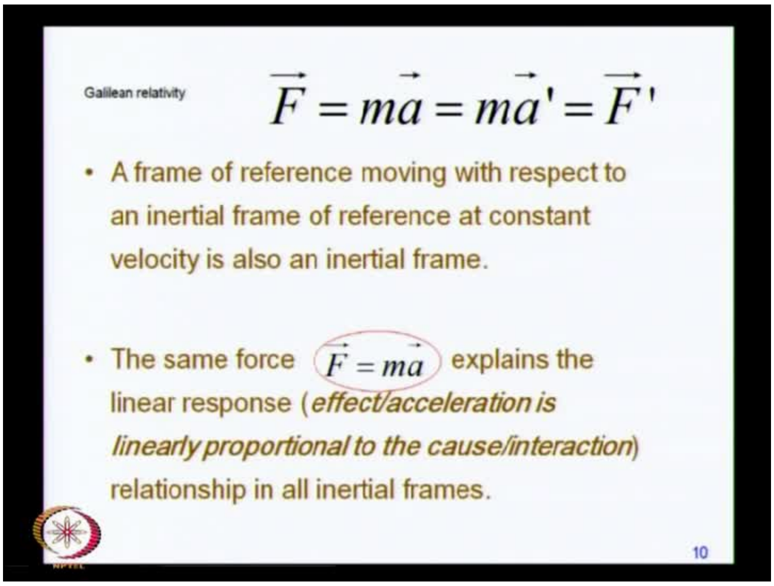
We now look at the second derivative, which is d 2 r by dt 2, this which is the acceleration perceived by an observer in the frame of reference F. He finds that it is exactly the same as it is for an observer in the blue frame, which is moving at a constant velocity, the two accelerations are exactly the same.

Which really means that it is the departure from equilibrium - if this is what interests the two observers, then they will not have to invoke different laws, because what they measure for acceleration that in the respective frames of references is essentially the same. Acceleration in the red frame, in the inertial frame, is exactly equal to the acceleration in the blue frame, which is moving with respect to the red frame at a constant velocity, a is equal to a prime.

Which necessarily means that if you just scale it by a scalar, which is inertia, which is the mass, then the equation f equal to m a and m a prime equal to f prime, each of these terms is exactly equal to any of the other terms. So, F is equal to m a, which is equal to m a prime, which is equal to F prime. All the four quantities that you see, the two forces F and F prime, the two accelerations a and a prime, scaled by the same mass, which of course remains invariant, when you go from one frame to another. A mass is excellent scalar; it is completely invariant, which means that the laws of mechanics are exactly the same in these two frames of references. You can therefore call the frame of reference F prime also as an inertial frame of reference, because the same law of physics is to be invoked in explaining the acceleration.

This is what justifies the high school definition that an inertial frame of reference is 1, which moves with respect to another inertial frame of reference at the constant velocity. This definition by itself does not mean very much, but it makes perfect sense, once you understand that the laws of mechanics are turn out to be the same in such frames of references, which are moving with respect to each other by a constant velocity alone.

(Refer Slide Time: 17:35)



Because, the linear response, which Newton invoked or rather Newton invented, this is really very fascinating, because we are making use of calculus, we are talking about the first derivative, the second derivative and calculus, they really did not exist before Newton.

Newton was just about 21, 22 years old, when he was observing planetary motion, to understand the angular orientations of these planets, he needed geometry, he needed trigonometry, then he needed the some idea of the rate at which these positions change with time. The idea of rate, which is what we are so familiar with because they teach us derivative in our mathematics classes, so we know what a derivative of a function, is.

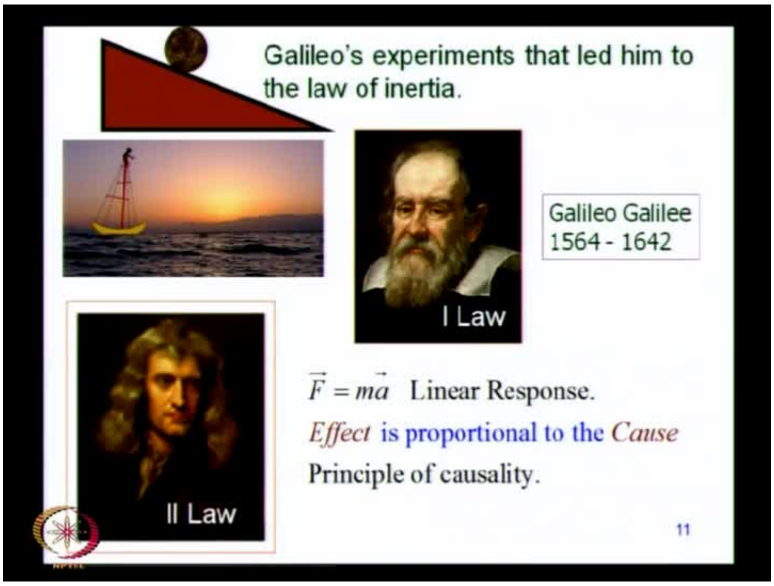
We know that this can be defined only when you construct a function, you need the function to be continuous, so you need the idea of a limit. Then, you take the change in the value of the function at two neighboring points, divided by the independent parameter difference. Then, take the limit that the independent parameter difference goes to 0.

Now, these ideas of limits and derivatives really did not exist before Newton, but Newton invented this, he invented calculus. Then, he explained that when there is a departure from equilibrium, it will result as acceleration, which is the second derivative of the position vector. This is then the result of some reason, this is where you need to look for a reason, as long as you do not find acceleration, you do not find that the second derivative is non-zero, you are looking only at equilibrium that does not seek a cause at all, because it is completely determined by initial conditions, you do not have to look for any cause. But, when there is a departure from equilibrium, you must look for a cause, this then results in the acceleration. So, acceleration is then the effect of a certain cause, you must look for this cause; it is this cause which Newton called as force. Newton went on to tell us that the result, which is acceleration, is linearly proportional to the cause, which is the force, so this is a linear response theory.

You got a stimulus which is the force; in modern language, we call this as an interaction. So, this is the stimulus, to this stimulus the mechanical system response by changing its state of equilibrium, which manifest as acceleration. This acceleration is linearly proportional to the stimulus, the proportionality is the inertia. So, F equal to m a, which is the linear equation, m being the mass, which is what we also call as inertia of the system. This is a complete statement of the linear response mechanism, which takes place between the stimulus, which is the physical interaction or the force and the response, which is observed as an acceleration of the mechanical system.

Now, what is fascinating is that the same linear response mechanism F equal to ma or F prime equal to ma prime. Exactly the same relationship holds in both of these frames of references, namely the blue frame of reference, which moves with respect to the red frame of reference at a constant velocity. So, the same cause effect relationship, this is the meaning of the statement that the physics is the same in all inertial frames of references, because the same physical interaction explains the dynamics, it explains the departure from equilibrium.

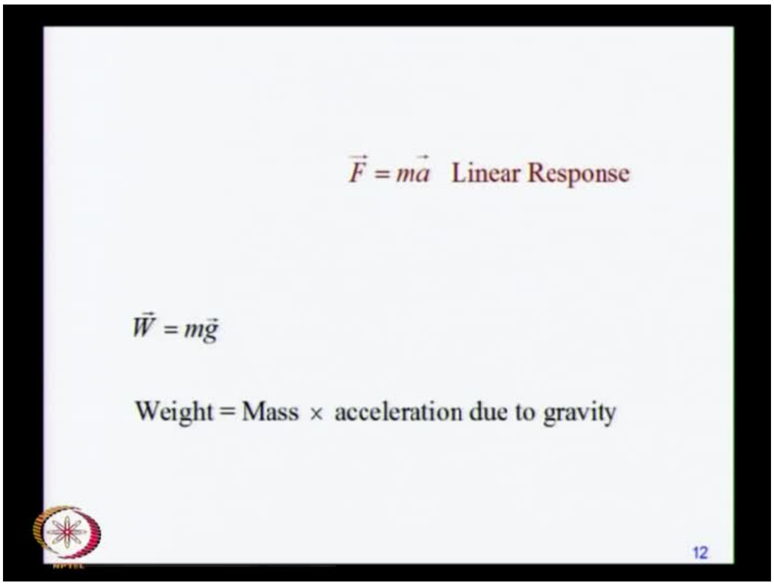
(Refer Slide Time: 22:21)



Galileo's understanding of inertia of course was fundamental. Galileo came before Newton; Newton was born the year Galileo died in 1642, Galileo had recognized that the state of rest, all of uniform motion are completely equivalent, he did it by carrying out these experiments by rolling, these spherical wooden objects on incline planes or by dropping objects from the top of a mast of a ship. Whether, you drop it when the ship is in motion or if it is duct or if it is anchored at some place, it falls at the same relative place.

By observing this, Galileo recognized the law of inertia, which is really very fascinating, because it is completely counter intuitive. Galileo recognize this and Newton factored it in, his understanding of how a mechanical system evolves with time. If it is in a state of equilibrium, then the initial conditions alone determine the evolution. If there is a departure from equilibrium, then Newton recognizes that there must be a cause, which will generate the effect that is observed is acceleration. This effect is directly proportional to the cause in this stimulus linear response mechanism. This is the principle of causality or determine is in classical mechanics.

(Refer Slide Time: 24:07)



Now, this immediately tells us that mass and weight are different things, mass is actually the proportionality, which goes into the stimulus response relationship. When the response is provoked by a cause, which happens to be gravity, then the interaction or the force is called as the weight. The response, which is acceleration, this is due to gravity, so it is called as acceleration due to gravity.

This is the relationship between mass and weight, it turn which we had used left, right and center, because every time people want to point out to me for good reasons that I have grown fat, they always tell me that your weight seems to have increased. What they really mean is that the mass has increased; mass is the actual quantity of matter.

(Refer Slide Time: 25:32)

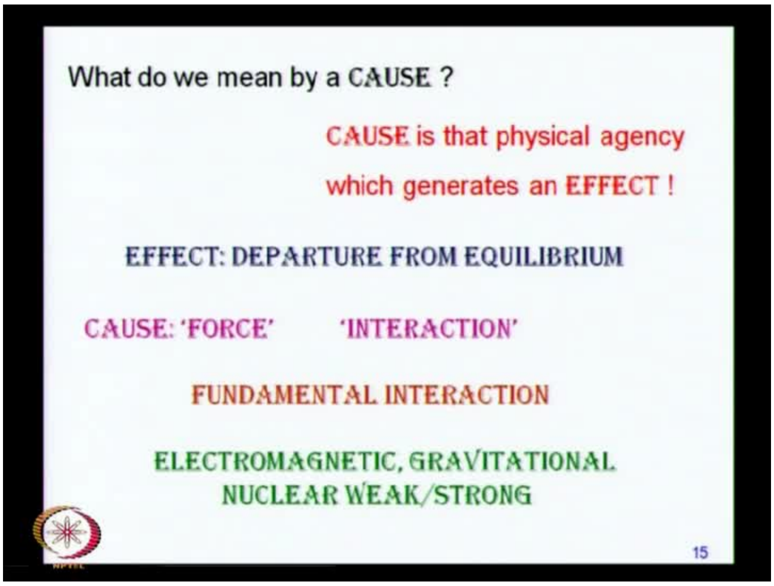
It is not a bad idea to quickly do couple of lunatic exercises, we will ask if lifting a cow is easier on the moon, it looks like a totally crazy idea, lifting a cow on the earth is crazy enough and lifting it to the moon is even more, so I would think. Actually a cow can be lifted there, are this commercial cow cradles which are available, one can actually purchase it. You know the answer, but I raise this question not to discuss them in the class, but just to highlight the difference between mass and weight, because in the moon the gravity would be a little weaker.

Here, you see this lady lifting the cow, but I am afraid, she is not lifting, she is probably preventing the cow from flying off, because is probably filled in with some gas that you're put in a balloon. So, she is not just lifting it, so these are fun lunatic exercises as we call them.

(Refer Slide Time: 26:40)

Let us do one more, if it is easier to stop a charging bull on the moon; this is a lovely painting by Russian painters Sorokin. It is beautiful painting, the question here is, is it easier to stop a charging bull on the moon? I let you think about it.

(Refer Slide Time: 27:06)



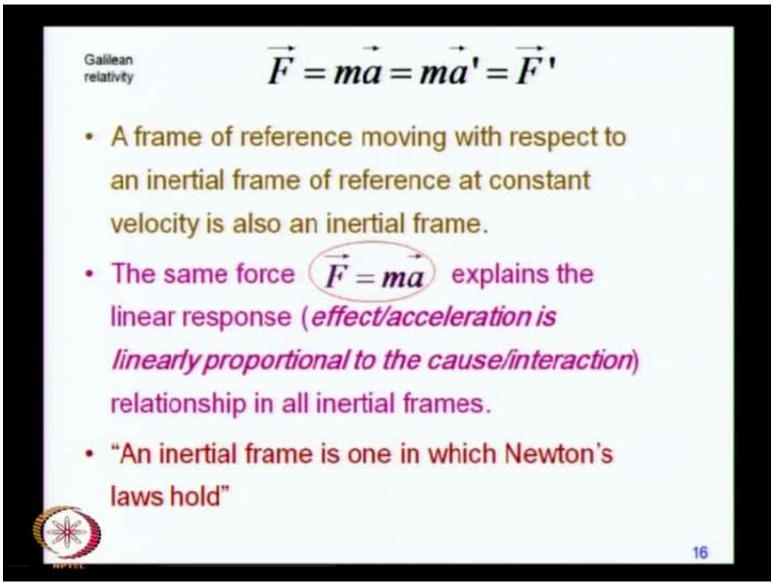
Now, we are in a position to understand what exactly is meant by a physical cause, what is meant by an interaction? A causes the physical agency, which generates an effect, simple. The effect is measured in terms of departure from equilibrium, because the state of equilibrium seeks no cause, it is self-sustaining and it is determined completely by initial conditions that is a first law of inertia.

It is only the departure from equilibrium, only when the momentum changes as long as the object continues to move at a constant momentum; you seek no cause, it is completely determined by initial conditions. Then, you may seek a cause only when you observe a departure from equilibrium, this cause is what we will call as a force or a fundamental interaction.

This can belong to only one of the four fundamental categories, it can be either way in electromagnetic interaction or a gravitational interaction or a nuclear strong or a nuclear weak. Of course, modern physics aims at unification of these forces, which is an attempt to understand that all of these forces are different expressions, different manifestations of the same fundamental interaction, which is what is meant by unification.

The cause which will go into this stimulus response theory will have to be a physical interaction; it will have to be one of these four fundamental forces. If you do not want to call them as 4, because electromagnetic and weak interaction has already being unified that depending on the level of unification, the number would be less than 4 - anything from 1 to 4, but it cannot exceed 4.

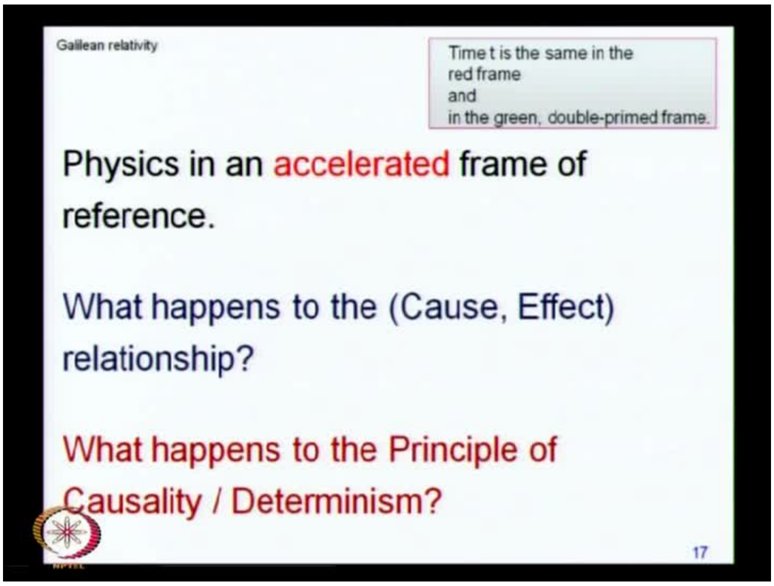
(Refer Slide Time: 29:34)



These fundamental forces can be understood only in terms of this idea, which we learn very easily in our high schools, but it really has a very Deeping impact on physics. Of course, quantum theory makes the discussion quite complex, so it is no more in terms of the stimulus response in the kind of the differential equation that you see from Newtonian dynamics. But, the basic idea of fundamental interactions still remains the same, which is part of the reason that this idea really needs careful discussion in college physics as well.

Now, we understand the meaning of this statement that in inertial frame of reference is one, in which Newton's laws hold, because this statement is caused in the context of this entire discussion that we have just had. All that discussion goes in the background or it provides a platform for developing what is a very simple statement that is inertial frame of references is one in which Newton's laws hold, but without this discussion, this statement really does not tell us very much, it is just like a definition.

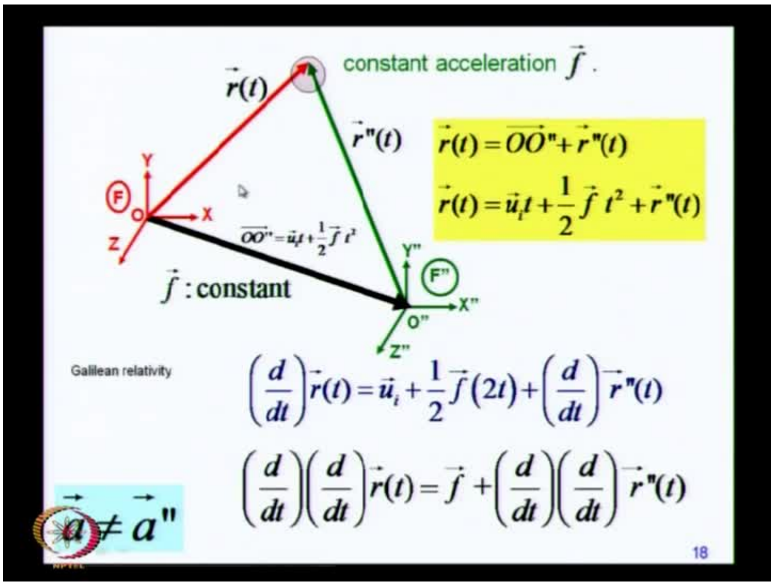
(Refer Slide Time: 31:18)



Now, in the previous frame of reference, in the previous case, we compared observations in two frames of references: the red frame and the blue frame. The blue frame was moving with respect to the red frame at a constant velocity. Now, we will let the second frame move not at a constant velocity, but we will let it undergo acceleration with respect to the inertial frame. So that brings us to discussing physics in an accelerator frame of reference.

At the question that we are going to have to rise is what will happen to the cause effect relationship? Will causality in determinism survive? Do these ideas survive in an accelerator frame of reference? The answer is both yes and no. I will explain why it is yes and why it is no when we discuss it further?

(Refer Slide Time: 32:30)



Let us now construct a frame of reference, which is this green frame, this frame F double prime, this move with respect to the frame O. Let us say, at t equal to 0, which is just when you start the clocks in the two frames of references, these clocks are Galilean clocks, these are not Lauren’s clocks. These - the Lauren’s relativity is what we will discuss in the next unit, which is unit 6 (Refer Slide Time: 32:40).

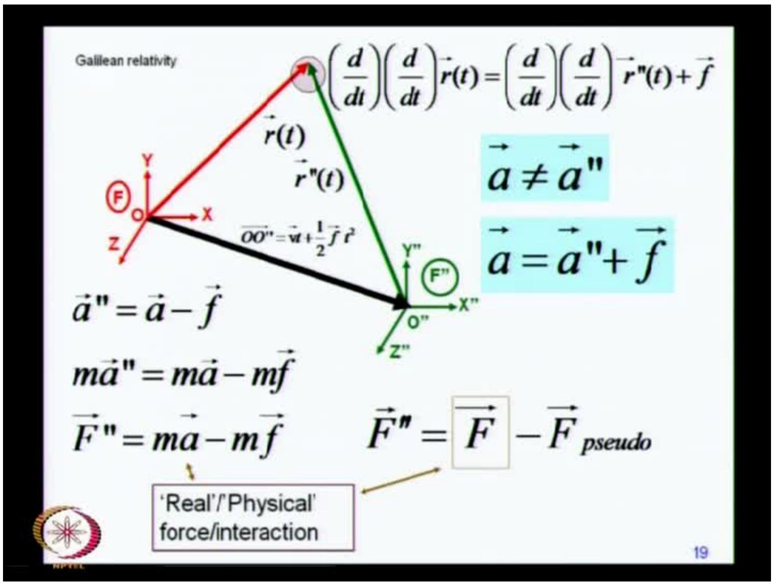
We are now in the realm of Galilean relativity, the two clocks, they remain synchronized in Galilean relativity. When you start the clock, the green frame and the red frame, let say that they are on top of each other. At t equal to 0, the green frame shouts of with a certain initial velocity u i and the constant acceleration, which is not 0 now, in the previous case it was 0, now it is not; so F is some constant acceleration.

The displacement vector between O and OO double prime is obviously equal to u i t minus half f t square, this comes from elementary kinematical equations. Now, you consider motion seen by an observer in the red frame, in the inertial frame of a certain object, which is here, whose position vector in the inertial frame, is r. In the accelerator frame, this position vector is r double prime; the two are related to each other by the triangle law of edition. So, r of t is equal to OO prime, which is this vector from O to OO double prime plus this green vector. So, OO double prime plus r double prime is equal to r, so this is the relationship that we get. OO double prime - this is the displacement vector, which is already seen to be u i t plus half f t square, so this is our basic construct.

Now, to get the velocity, you take the first derivative with respect to time. This is a simple differentiation, on the left hand side u get d r by dt, from differentiating u i t, you get u i, by differentiating half f t square, you get f times t. The factor two will cancel in the denominator and this one and then you get the velocity as seen in the double prime frame of reference, which is d by dt of r double prime.

If you now take the second derivative, you will get the acceleration and that is what will be a measure of departure from equilibrium, this is where you are going to look for a cause. You take the second derivative, so here you have the second derivative on the left hand side; on the right hand side, the derivative of u i vanish, because it is just the initial velocity, which is some constant number, so its derivative with respect to time will vanish. From the derivative of f t, you get f and then you get the second derivative as seen in the double prime or the accelerator frame of reference.

(Refer Slide Time: 36:46)



In other words, the acceleration in the frame red is not equal to the acceleration in the accelerated frame. The acceleration of the object under investigation, which is this object we have, this is the object, whose mechanical state is being observed by two observers. The acceleration of this object is different in two frames of references, a is not equal to a double prime, the relationship between them is a is equal to a double prime plus f. Now, the observer in this green frame, which is the accelerated frame, what is he thinking? He measures acceleration in his frame, which is a double prime and it is equal to a minus f.

So, m a double prime, if you just multiply this by the inertia of the system, which is the mass of the system, ma double prime is equal to ma minus mf. This is what the observer in the green frame will recognize as the force, so his idea of force is not the same as the idea of force in the inertial frame of reference.

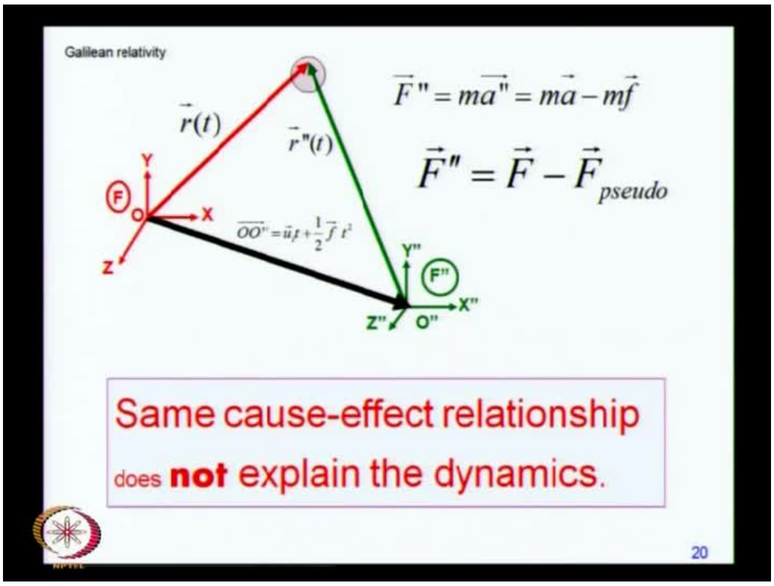
In other words, if m a which is the mass times acceleration, is what we regarded to be equal to the physical interaction from Newtonian dynamics, in the inertial frame of reference. This is what gave us several idea of force; if this is what gives a several idea of force, no matter what it form as electromagnetic, nuclear strong, weak or gravity, it cannot be anything else, it has to be one of these.

If this is what is recognized as force, then this quantity over here is obviously not a fundamental force, because the idea of fundamental force was developed in the inertial frame of reference. But, to the observer, in this double prime frame of reference, which is what we call as the accelerator frame of reference, to this observer, the acceleration of a double prime is a completely real phenomenon. It is a measurable thing; it is what he measures in his own frame of reference as the departure from equilibrium.

He finds that it is equal to mass time’s acceleration in the inertial frame, less and a constant quantity, which is m times the little f. If this has already been identified as the fundamental interaction, then this is obviously just a mathematical art effect of the fact that this frame of reference is accelerated with respect to this; there is no physics in it.

It is not the result of a physical interaction; it is a result of carrying out observations in a frame of reference which is not in an inertial frame of reference. So, whenever you do that you will find that the mass times acceleration in an accelerated frame of reference, will not be equal to the physical force, but it will be different. The difference in this case is what I have written as F with the subscript pseudo, because it is not a real force.

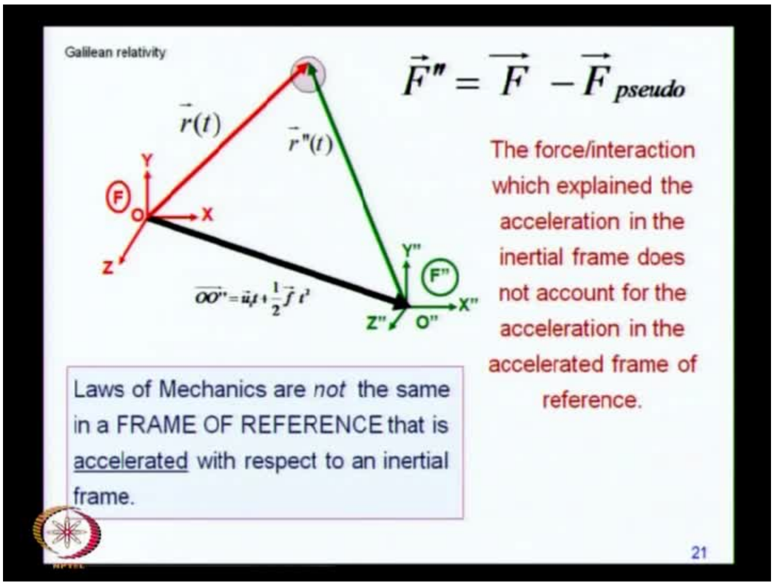
(Refer Slide Time: 40:26)



What happens to the principle of causality? The cause effect relationship, which was linear response equation, acceleration was proportional to the cause and the proportionality was the inertia.

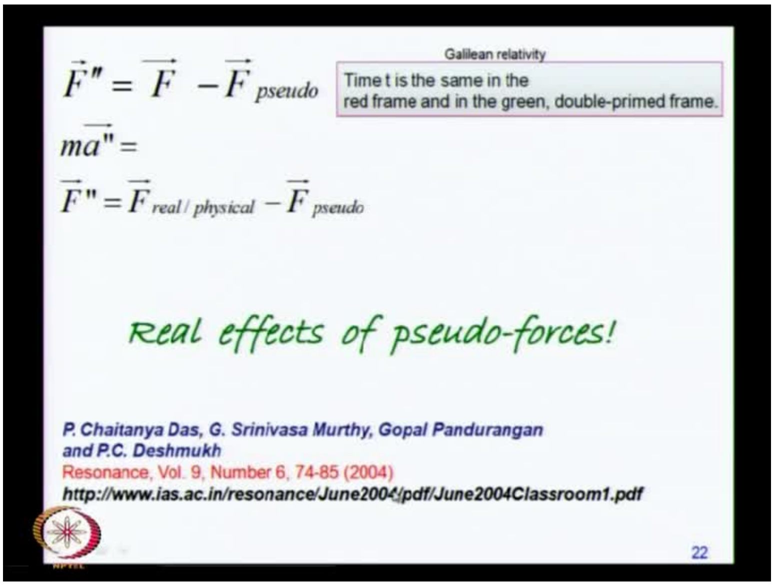
Now, that relation has to be modified, you can sort of modify that relationship by inventing this F double prime, which is the difference between F and this mf, which is F pseudo. This difference is what you can call as the net pseudo force, which includes the real interaction to a certain extent, but it also includes a mathematical construct of the fact that the observations are being carried out in an accelerated frame of reference.

(Refer Slide Time: 41:41)



The same cause effect relationship, which explained dynamics in the inertial frame of reference, does not do so any more in the accelerated frame of reference. Which also means, the losses of mechanics are not the same in these two frames of references, this is the meaning of the statement that the inertial frame of reference is one in which the laws of mechanics hold. Now, we see what that statement really means? Because, we find that the laws of mechanics cannot be stated in the same form, they must be modified if you have to recast them in an accelerated frame of reference.

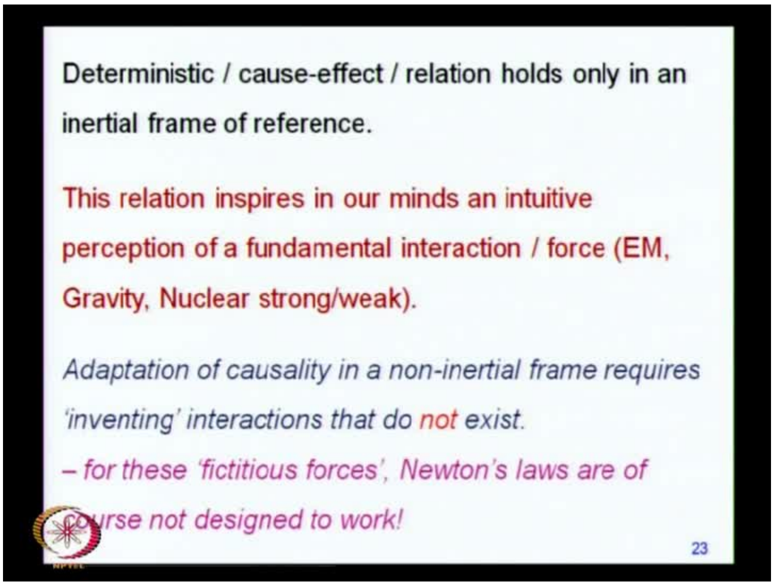
(Refer Slide Time: 42:21)



So, this is what we called as the real effects of a pseudo force, because the observation a double prime is very much real to the observer in the accelerated frame of reference. You can write F double prime equal to m a double prime, in which this is now your idea of the physical interaction, but this idea of the physical interaction includes the real force F less a force, which is not a physical interaction. F pseudo cannot be reduced to any fundamental force like electromagnetic or gravity or nuclear strong or weak.

I will invite you to read this article, which some of my students have written. In particular, Gopal Pandurangan was the first want to do this; subsequently this work was done also by Chaitanya and Srinivasa Murthy. This article is available at this link, this is the title of this paper that what you see are really facts of pseudo forces; the effects are real, the cause is not.

(Refer Slide Time: 43:51)

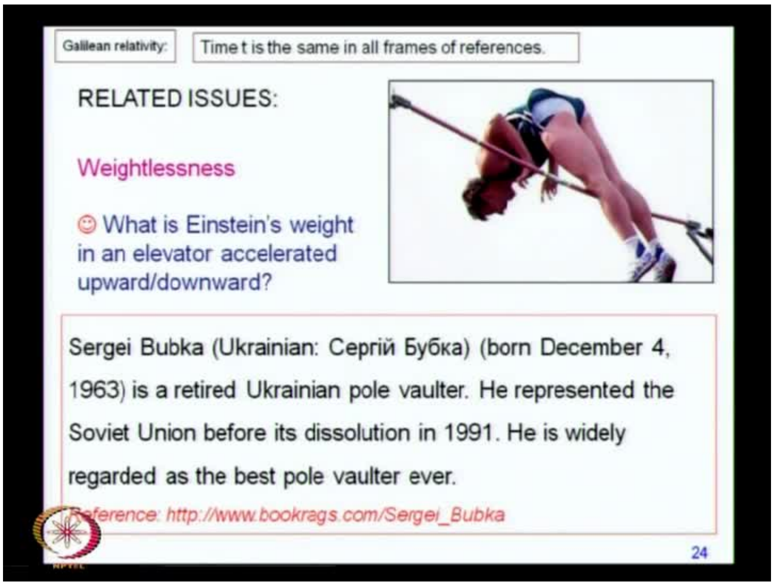


You can sort of restate the deterministic cause effect relationship, which really holds only in an inertial frame of reference. It is this relationship which generates in our mind an intuitive perception of fundamental forces. Once we recognize this idea of a fundamental force, then we only study its form, whether it is electromagnetic or nuclear or gravity or some unification there off, these are different forms. But, the idea of a fundamental interaction comes essentially from the perception of an inertial frame of reference.

If you want to somehow force causality in frame of reference, which is accelerated, because you always like to reason out in classical mechanics, the entire domain of classical mechanics is inspired by causality that you look for causes. You think that there is a cause, which explains the result.

If you seek similar relations in an accelerated frame of reference, then you can do so only by inventing causes do not exist, so these are the pseudo forces. You can invent the pseudo forces, these are fictitious forces and obviously Newton's laws are not designed for these fictitious forces. So, they can be used in some sort of Newtonian formulation of mechanics, but they will include these pseudo forces, which are forced into our thinking by the fact that we are explaining observations in an accelerated frame of reference.

(Refer Slide Time: 46:06)



There are related issues like people talk about weightlessness, you experience this all the time. Means, if you carry away in machine with you in the elevator, when you come to this floor, we are now on the third floor. This experiment is more interesting, when the elevator is accelerated rapidly or while going down, it is again accelerated, but the direction of acceleration is different. In one case, when the elevator is going up, the acceleration exits against gravity, when it is going down, it is in the same direction as gravity. If you weigh yourself on a weighing machine, you are going to record different weights.

The idea of weightlessness is connected to the fact that observations in an accelerated frame of reference, it will not be explicable in terms of the same fundamental interactions, which are invoked in inertial frame of reference. This is in fact very nicely exploited by sport speaking. Here is a picture of Sergei Bubka, who is retired, but one of the most famous pole vaulters of all times.

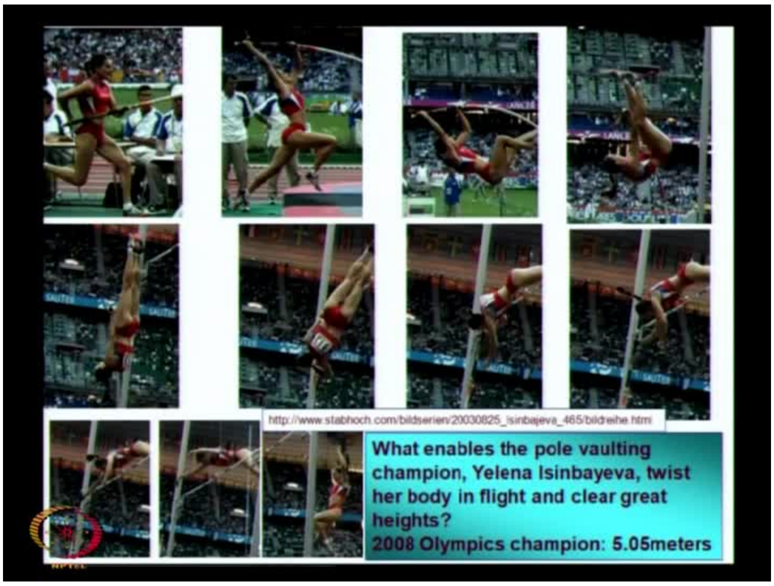
Now, look at the allegiance with which he goes over the bar. By flexing his body, means he has got his arms and limb, which he can position. I can hold my hand here, I can hold it here, I can hold it here, but where I am holding it will determine where my centre of mass is. Unfortunately, it will not reduce my mass, but at least it can change the position of the centre of mass and that can be done simply by changing the position of my limbs.

What he manages to do is by flexing his body he can led the centre of mass, go a little bit lower, then where he otherwise has to raise the entire body to that point, if he wants to clear a certain point. He can in principle allow the centre of mass to actually go below the bar, let the body go above the bar, as long as he can flex his body suitably. The energy he needs to raise a centre of mass above the bar is obviously much more that what is required to raise it to a point below the bar.

Now, I do not know if he where his centre of mass actually goes by, does it go below the bar or above the bar that is a matter of detail, but it is quite clear from this discussion that it is not necessary to raise it to the highest point, you can let it go at a lower point. This becomes possible, because his control on his limbs is so easier in this state, because he is in a state of what we call as weightlessness.

He is in a state of free fall, all parts of his body are falling at acceleration due to gravity at j. So, what he has to overcome is just the inertia of this part of his body by his muscle power and not the weight of this. That is a difference between mass and weight. He has to manipulate just the mass and not the weight, because the entire body it is in a state of weightlessness, it is in a straight of free fall.

(Refer Slide Time: 50:45)



We can exploit it, athletes do it a very nicely. Sergei Bubka is one of the best known pole vaulter, so I had his picture, but may be you are familiar with some of the modern pole vaulters. This is the one who got the Olympics gold medal in 2008 Yelena Isinbayeva, how do you pronounce it? Vivek, do you know how to pronounce it? I do not either. This is the Russian name; she cleared 5.05 meters in the 2008 Olympics, exactly the same thing. In the kind of agility these athletes have in manipulating the limps, is what distinguishes them from ordinary people.

So, I guess we will take a brake here, if there is any question I will be happy to take it, otherwise we will take a break, we will continue from this point. In the next class, we will continue the discussion on real effects of pseudo forces.