

Hi this is HC Verma from IIT Kanpur and I am here to give this special talk on experiments All around these classical mechanics electricity optics rules before our eyes

so it is a great opportunity to learn the laws and equations of physics through all these small phenomena and everything that is happening around them and manipulate them a bit. Tune it to our own syllabus

so that the subjects we study understand the laws and then enjoy all these equations together with natural phenomena

so most of the experiments I will show today will be such that you can design them as you like. House and you can perform that we did most of them and you can enjoy and you can come up with more new experiments

so I will take some 3-4 things one is friction another is non-inertial frame and pseudo force then we rotate and I will probably talk about a little resonance in a forced swing

so I start with a simple test that is in a textbook that has been in literature for a long time maybe five six or seven decades and it is known as a card coin test and by this name you probably know what test I am talking about you Take a glass you take a card you put a coin you shake the card and the coin falls into the glass tumbler and it is known as a show of restless inertia,

so I will start with this but the discussions will be a bit different from the traditional And this important item of my experiment can be found anywhere in your home or in the tea shop or in the alluring store, then I have a few gad I have a long size card I have a small size still small size we have several cars so another part and the third part is this coin this is a coin here

so the test here consists of placing a card in this tumbler

so I keep this card in tumbler And then this coin goes here and on this card almost above the center of this glass tumbler now the prescription is you shake the card and then the coin has to go to tumbler

so let's see what happens oh it didn't go to tumbler tumbler is still empty and coin is right out here

so I have the same again Let the card and the same coin do it again and let me do it again This time it goes to Tumbler OK

so let's take a longer card Let's take this card Let's put this coin here and then shake it out Let's go in You see, the coin goes to Tumbler sometimes, but not to Tumbler. It has its own location and if that happens when the card slips then the coin should go to Tumbler because in our tests sometimes it goes to Tumbler sometimes it doesn't go to Tumbler

so there is something else involved with it and let's see what a You must have guessed that some friction is this friction between this card and the coin.

When this card goes out like this, it slips the coin on the card. What happens when I flick this card goes into the front of the card and then The friction of the coin will be towards the front because once it slips, the friction of the coin will be towards the front because it is sliding towards the back of the card. What happens is that it falls out larger than the radius of the Tumbler, and if this movement is less, it goes to the Tumbler, but in all cases there will be friction between the coin and the card. This friction will move the coin forward. The displacement may be small but it is always there. You can make a guess. You can write your equations and find the conditions that it will go to Tumbler and in any case it will go out of Tumbler

so you must. It is in the main course of mechanics that Newton's first law of motion and the second law of law are valid, you can apply it in that specific form only in the inertial frames of reference if you have non-inertial frames you need to use some pseudo power if you still apply $f = ma$ So if the

frame moves in a straight line the accelerated frame moves in a straight line so the acceleration is linear no rotation of the frame is involved then the pseudo ball is very simple le that the pseudo force is only minus m times a void where the mass of the object under m study is a vacuum A kind of artificial construction you take the mass of something else, accelerate something else and then multiply and place a minus sign but in any case if you frame non-inertia Want to use and use Newton's formula but you have to bring some artificial things

so that's why if you combine this ball with real energy you can still analyze things

so let's do a test on it

so here's a plastic box and What I put in this box is that this kind of pulses sometimes it becomes a rare product and it spreads all over the base and I close the lid of it. Now let's talk about this box frame and I 'll give an acceleration to the side where I put the box. res I will speed it up in this line to give acceleration and you have to look carefully and see what kind of motion occurs with respect to this box OK

so again it is at rest and it is spread almost evenly on base and then see if they are moving left or they are right What kind of motion is it moving forward

so what you noticed at the beginning you saw that these pulses are accumulating in this direction

so they had an acceleration in the frame of this side and this implies from our equation the acceleration is left in this direction .

On the opposite side which is to my right and

so because of that pseudo ball these particles were accelerated to a right side and things freeze but then you also see that things are finally deposited on the opposite side if you don't see it then see it again What's happening is that more particles have accumulated on this side

so in that second half the pseudo ball on the left by me

so on this side and it must be like this because if I was accelerating then I gave it a velocity then I stopped it in the second half too

so if I stop it is a kind of erosion and acceleration is the same story as I saw the pseudo ball on the left side as opposed to the velocity

so the same story but uh this time in different packaging

so i have a bottle or a pot and the vessel is water to me There is and a ball is hanging in the water. The ball is hanging and the thread is fixed with the lid

so it rests. Now the net ball is zero. Again this box will be our frame. And since it is at rest, the result is \emptyset and all these things now I will accelerate this box to the left again as I saw and you can see what happens to the ball.

Go first. Go first. The widths are quite small

so look at the direction of the first throw I'm moving it to my left it goes first and it's ok to hit this wall

so since I'm accelerating it to the left the pseudo force right Who has it and it deflects this ball to the right and goes and hits this side of course it swings and then all those things happen

so last time it goes right again and it is hitting here now a second version of this test again a pot to me again I have water again I have a ball Yellow ball but now this yellow ball is not hanging from the lid This yellow ball is attached to a thread. At the bottom of this box this yellow ball is a tennis ball and it is lighter than water

so it floats in water and since We fixed that thread at the bottom. It's just in the middle

so you can too. I believe you can see the thread at the bottom of this yellow ball. You can see the thread going down, so again the frame will accelerate to the left. On the way you can see the first throw where the ball moved to the left or it went to the right acceleration. The initial acceleration to the left is at least to the left so it goes to the left. Acceleration should have been on the right side so what is happening here is what is happening here with this pseudo energy. When you accelerate this ship you also have real energy. The pressure of this water is not the same left and right. Level pressure The pressure is the same at all points on any horizontal plane so the pressure on this side up and down is different but if you go this way the pressure is the same but once it goes to one side and you have pseudo-energy and those pseudo-forces Trying to push the water in the opposite direction and so the pressure in this direction increases the pressure decreases in this direction and you have a real ball because of this pressure difference you have a real ball and that real ball dominates the pseudo ball, this ball because of the pressure difference More than that pseudo ball in this case and so if you write $f = ma$ with pseudo power the total net result including real forces is a final result of everything you do with the force on this left side and thus it is on the left side. The reaction is OK so the next test on this non-inertial frame is linearly accelerated. I have a plastic box here and I fixed a small black ring magnet on the lid. Here it is fixed to the lid using this double sticky tape I have another similar black ring magnet and if I close it here these two magnets are a magnet here and a magnet here they are in attractive mode the poles of the face have different polarity and so they are attracting each other but these are weak magnets and here the force of attraction of distance is very Less and so the weight of this ring is much higher than that small force of attraction and so it is located here The box frame is now an inertial frame so you can use all your Newton's laws there. This is a normal reaction force from the bottom, then there is weight then there is a small faint attraction from the top magnet and the total is zero and so this magnet rests on this box subject to fra I do what I will just drop it from here This box will become a non-inertial frame an accelerated frame and the acceleration will be about d at the bottom and in that accelerating frame in the falling frame you can see this lower ring magnet. So now I'm going to drop it and try to see how that lower magnet goes. You probably won't be able to see it in the box but there's something else you can figure out what's going on with this lower ring magnet so I'm dropping it . Where is that magnet where is that ring magnet where is this ring magnet it is not here so it is up and stuck in the slide now you have two of them you started with one but now you have two so at T goes and gets stuck here and when it goes and it sticks it's a sound it's when it goes and it sticks a sound so I'll repeat this test and you follow the word because that word says when it goes and hits so I I'm doing it again and you're following the word OK I drop it as soon as you hear that word you hear the tick in a very short time so this lower magnet in the box frame goes up and a stick to get stuck with

this upper magnet So if I analyze from the frame of the box then what I will say is that the box is taking an acceleration g .
 There is a pseudo ball on top of this lower ring magnet at the bottom and how much is the mass on the board. So what is happening is the acceleration of m and the acceleration of the box is about g
 so the upward direction of mg
 so the actual force mg that the weight that is going down is just canceled which means it is going to go with the box g acceleration
 so it is being canceled by these ps which Yudo ball
 so weight and pseudo ball that sum is zero
 so let me make it on board
 so I'm talking about this magnet this is a small mass of my object m
 so pseudo ball is the subtraction mass of the object and the bar acceleration of the frame
 so this acceleration of the frame is g and the mass of the object is m
 so this is but then you have a real force weight which is a minus mg and it's plus mg
 so it's plus mj
 so that means you have a mg force that is upwards and here is a mg ball that is downward and then you have this The magnetic ball is a very small weak magnetic force of attraction and it is upward
 so I am talking about this ring magnet that attracts the upper magnet which is sitting on the lid here
 so that the small ball has this magnetic force weight and then there is a normal force. But when the motion starts it goes to zero
 so these two are canceled and this is the only energy left
 so the acceleration of this ring magnet with respect to this box is equal to the mass of acceleration which is coming here and it is going upwards because net ball is going upwards
 so it goes up and it goes up. That's why it hits the magnet This phenomenon is sometimes called weightlessness because the weight is canceled out by the pseudo ball
 so if you are in a freely falling box in a freely falling frame you forget to apply pseudo ball and you also forget to apply weight and still your Newton rules are right and you Feel like there is no weight
 so this phenomenon is sometimes called weightlessness OK
 so another type of non-inertia frame that you must study is the reference rotation frame if your xyz axis is in the frame of the lap these axes rotate themselves with some angular velocity ω and If you are analyzing in that frame then you have to apply specific pseudo force one of them is called centrifugal force. The expression for nd you must make that centrifugal force you write it as $m \omega^2 \times r$ and take these quantities as axis of rotation and frame Anyway you can put a disk. Suppose you have a disk and the x axis is marked on the disk. The z axis is marked on the y axis and it is something near the z axis Angular velocity rotates with ω
 so ω is the angular velocity of the rotating frame of the frame and this r is the distance of the object to the axis of rotation and this m must be the mass of the object and what is the direction of this ball from the axis to the outer side
 so it is a pseudo ball
 so I have a disc here and this The disk can rotate this disk to the right
 so this disk will be our rotating reference frame. We can mark the x axis y axis in it. You can say that k is the x axis. This rotates the x axis and also rotates the y axis in the frame and here the axis of rotation which is the z

axis is the axis of rotation

so what we want to analyze in this rotating frame

so I have a tube here a long glass tube I must have this long glass tube closed here and Here we closed it with a cork. It has water in it and in the water you can see there are certain red particles. Here it is. Here you can see some red. There are things that are at the bottom of this tube here and then you will see some white. These white parts are white particles and these are a yellow here

so these are foam particles. The particles of this rock are the particles of rock which are the particles of rock which are at the bottom and they are distributed all over this tube. You will see a particle here. A particle here is a particle. OK let me give it a spin

so you can see where the white foam particles are that were distributed along the length you see they are near the center they are all near the center there is actually an air bubble in the center And all these foam particles are near those air bubbles and where do you see the red stone particles looking for those red stone particles ? The redstone particles that were distributed along the length and now you can see that all of them are either deposited at this end or the rock particles at this end have moved outwards. Energy means a centrifugal force externally and it carries away the rock particles but how do the air particles come? Coming to the center and how these four foam particles are coming to the center again there is a difference in water pressure in your rotating frame, there is also a difference in your pressure there is more water pressure near the edges and less pressure near the center and the force of pressure difference is internal Coming to the center determines who will dominate which pseudo ball is greater or the pressure difference is greater will decide which particles will come towards the center and which particles will move away from the center

so let us do some experiments with rotating. When a sphere or something rolls over a surface, different particles of this object move to different speeds. The contact velocity of the point of contact is zero which is when it is purely rotating

so this surface is fixed this surface is fixed and if this is v_n the zero velocity of the contact point is not zero then it will slip and pure rotating means there is no slippage and

so this v The contact should be zero where the center must be moving with some velocity v_c and if you look at the vertex it is moving with some more velocity, let's say v_{vertex} if you see some point somewhere here that is moving with some other velocity which is different velocity So different points move with different velocities and a simple rule is to take this as the instantaneous axis of rotation through the point of contact and then you can use r equal to r ω to find the velocity

so if you look at the vertex of this point this distance is $2r$ Multiplication radius If you look at the center, this distance is the radius. The v_{top} is ω in $2r$ and the v_{center} is ω in r which means v_{top} is a cylindrical object equal to 2 times it is just a PVC pipe which is usually used for many purposes and I am placing it on this horizontal surface and it can roll here. Can roll here

so I put it on the edge and there is a plastic scale here and I put the edge of the scale right here and in my test push the scale gently and press this PVC pipe

so that there is no slipping between this scale and this PVC pipe. It will not slip just like that

so I will just press it gently and push it slowly. You can see that the PVC

pipe is spinning and spinning. The speed of the point is the speed of the part of the same scale that is in contact
so if it is here and I am pushing it at this point if the speed of this part of the scale here and the speed of this part of the PVC pipe is not slipping here. It has to be the same
so it has to be very well understood OK
so now I start it you see where the end of the scale and the center of the PVC pipe are both at the edge of this table
so this is the starting point and now I'm removing it I am pressing it at the same time I'm moving it and I'm not letting the highest point on this scale slip
so I got here to see how far the center of this PVC pipe has moved from this edge to this point and how much the scale has moved this edge look at this edge this edge was here this edge was here and From here this edge has reached here so the scale has moved from the edge to this point where the center has moved from the edge to this point and if I measure this distance here it is again a scale 30 cm
so the center of the PVC pipe has moved up to 30 cm here and this length is 30 centimeters
so it moved 30 centimeters but then the scale moved this 30 centimeters plus this 30 centimeters moved 60 centimeters
so you can see Note that at the same time the center moves 30 centimeters the vertex must have twice the velocity because there is a scale that always moves and the vertex of the vertex point moves 60 centimeters and
so v is twice the vertex of the vertex. You must have achieved the expression of acceleration when a sphere or a cylinder or a disc is rotating in an inclined plane
so if you have this curved plane then some inclination and suppose you have a sphere here but if the friction coefficient is sufficient it can go down with pure rotation So it can rotate it can move and as long as you have v is equal to ω time r and the center acceleration is α multiplier r as it is angular acceleration it is angular velocity it is linear acceleration of the center if these conditions are satisfied you say it is pure rule
so you Or you must have worked out what its acceleration will be
so it depends on the moment of inertia if it is sphere you can determine what acceleration it is if it is a cylinder or a disc but you can find out what acceleration if it is There is a loop ring but you can figure out what the acceleration is and to do this you have to write the force equation write the friction and remember the friction is not μ times n because it is a fixed friction that is here
so The only friction you need is there and then you write the equations all these elements and do the equations for the center mass and then the equation of angular acceleration and then apply these conditions and you can find all these things and they are different and you must remember that This acceleration of the sphere will be greater than the acceleration of the desk or vice versa you will correct it I will show it here
so I have made a prototype of the approximate inclined plane it is nothing but the channel PVC channel used by plumbers and electricians and I have raised a side
so that it is approximate Either ly a leaning plane is definitely not flat due to its own weight and then I have two objects one is this cylindrical object or a disk type object this you also know it is a carom coin and the other is this raw glass ball that you are familiar with
so The idea is to compare the time of rotation of these two inclined planes

so to me this ball is here this round ball here it is that raw And the disk is placed here and then I put this scale here so that when I lift the scale these two things will rotate along this inclined plane. The sphere came first. Now let me reverse the sequence. I put this coin in front and they come together behind this spherical ball. So the acceleration of the ball is high but when the ball is behind and the disc is in front they come together not very unnatural because the acceleration of the ball is high and it has small acceleration so the ball is pushing the disc No, or whatever, five by seven, they're down, and so they 're coming together, so our next display test is on the angular momentum torque, and especially the vector character, so you know that The linear momentum is given by the cross $\mathbf{r} \times \mathbf{p}$ The angular momentum is given by $\mathbf{r} \times \mathbf{p}$ Of course these are a force and for a particle this linear momentum You have many particles in a rigid body so the total angular momentum you need to add these quantities and for the total torque You need to find the torque of each force and then add and the important relation is that this $d\mathbf{L}/dt$ this torque is nothing but the Change This is an important issue and in our experiments we will try to look at it especially the direction part now. Here in the setup I have used a disc CD disc old CD disc and it is mounted on the spindle of a motor it is tape recorder motor and we mounted it here then with this motor we sold the tape battery a cell 9 volt and one end of the motor is already This is attached to the battery and the other end if I touch it here this motor will start to rotate and the disc will also start to rotate so you can see if the direction it starts moving is going clockwise. It's going counterclockwise as you see it, so let me just connect the motor and you'll see the rotation first, so when I connect it, it's okay to go in any direction, so remember you saw it going counterclockwise. \mathbf{r} and if it goes counterclockwise then the angular momentum will be towards you if it goes counterclockwise then the angular momentum will be away from you if it goes counterclockwise then the angular momentum will be towards you and then this whole thing is hung using The thread of this stand here is the clamp stand here so this other end of the thread is tied here so that it can just hang and this point where we put this thread is tied to this thread This point is specially selected if the disk surface is vertical if this disk surface is vertical this point is this The motor is the heaviest part here so it should be somewhere near the center of mass of the system and the center of mass will be somewhere. Tied to this point away from the other side of the desk so this is fine so this setup let me analyze the situation first if i let go of this disc then i hold this disc here using my finger and thumb if I let it out of here Let me tell you what, and how I will analyze what would happen if you let go of the disk, it was like this and you let go and the disk goes away so it rotates, so the disk is now in this vertical plane and if I leave it like this Rotate so as soon as it is going counterclockwise from this direction OK so the angular momentum is zero here and then it is rotating counterclockwise as seen from this side

so angular momentum is generated

so what is the direction of change of angular momentum it has this aspect
Whether the weight is coming from the cross, let's take the torque about the center of weight here

so there will be no torque of weight here because it is the center of mass and what is going through this thread there

so you have a r vector from the origin up to the point where this force is working

so it is that r vector and it is that ball f vector

so if you have another vector then something like this if you have r vector then what is this r vector? The point at which this thread is tied from the center of mass is the r vector point of force applied to this force and here you join the point of application from the center of mass here it is r and it f

so $r \times f$ is actually coming this way and

so the torque The change in direction and angular momentum is the same as the need for equation. What happens if I attach this battery to the battery and it starts moving and remember its motion is counterclockwise again

so you have a large angular momentum on this side and your big angular momentum on this side. Coming out and if I let it go if I move my fingers what will happen here with torque let me analyze first and then show ok

so if you already have a big angular momentum in this direction and then if this rotating force There are if I remove all my fingers then it will only be this rotating force and this rotating force we have already worked the direction of this rotating force is like this is r vector and f ve Cutter and torque are right on this side

so change of angular momentum should be in the same direction

so suppose your angular momentum is already here the disk rotates fast and then change of angular momentum is like this is a small change of time dt because this is the direction of torque workout $r \times f$ So what will be the direction

so the new angular momentum at $T + \Delta t$ is this angular momentum then it changes the direction of torque dL and if you take the result of these two then it will be like your parallel thread it will be something like this so new angular momentum must The new angular momentum in this direction means and rotates faster

so the disc should rotate if the angular momentum is rotated and the angular momentum is perpendicular to this plane

so the whole disk has to rotate

so it will go this way

so what I expect from the theory is that it rotates Otherwise it falls if it is rotating but it will not fall it will just rotate

so let's see if it is

so now I am moving my fingers and you can see what happens to the plane of the disc it is not The plane is still vertical and it is making this rotation to show that yes torque changes angular momentum and angular momentum changes rotation. The transmission is towards the ball

so it is essential because when you ride the bike you can easily balance the wheel that rotates when the bike rotates but if this bike cannot move if this wheel is not rotated and you do not have a stand on your bike you can use it.

Can't decide. Here it will now fall The last display of the session is on forced oscillation and resonance If you think a pendulum system has its own natural frequency it may have multiple natural frequencies

so if you apply an external alternating force and then the oscillations are under it then force it Is called oscillation and if the frequency of this

external periodic ball is close to the natural frequency then the amplitude increases OK

so you have a pendulum system and it has its own natural frequency which you call ω_{nat} and this natural frequency comes through the restoring force mechanism Let it be

so that it decides that you can have multiple natural frequencies but sometimes you have only one natural frequency and then you apply an external force which means that the force that may be there without any dampness outside the restoring force is an external force. Apply and if it is periodic If it is also periodic and its frequency is ω then if ω is close to ω_{nat} then you have a large amplitude called resonance and if these ω and ω_{nat} are significantly different from each other then the amplitudes are smaller and I have an operator here So I have a wooden block that has a groove here and in that groove I fixed a long straw. We made this long straw by combining several straws and then this edge is pushed into the groove

so this is the swinging system you look at the tip here. And if I oscillate it must be very damp with movement but before it stops it oscillates with a certain frequency it is a natural frequency and I can apply an external alternating force on it using my hands

so now look at my hands below I just point to the fingers Let's take a look. I'll give this motion a periodic motion

so that this block applies a periodic force on the straw here

so I'm just like this. I can move the speed OK

so let me start first very low frequency of my hand look at my hand first

so I will move it this way you can see I am moving my fingers or you can see

this end of the block I am moving this block with very small frequency And I will continue this frequency and you look at the edge of this straw to see how the edge is swaying towards the top. How it is swaying. What is the amplitude?

Look I am swinging this stand this base with a very high frequency and now

look at the edge look at the edge how much width is not and next I will swing my hand I apply periodic force with a frequency which is close to natural frequency

so first look at my hand Look at the hand and see what kind of swing I am giving to the base of this wooden base Look at this frequency and see the displacement width of this straw. How big is the width

so at this point the external periodic force has a frequency which is close to the frequency of the natural frequency of the straw and the amplitudes are very high but if I increase I increase the frequency then you will see that the width is really. The amplitude of the oscillation is also very small if I make the frequency of my external force very small but if I make this intermediate frequency very close to the natural frequency then the amplitudes are very high and it is known to resonate well

so I am concluding this session I hope you Enjoy the natural phenomena that surround us that we can put together in a very simple way and that illustrate your many physics principles Learn your theory class Thank you