

we will continue with our discussion on forces on bodies we will look at some problems and today in addition to looking at one or two simple problems what i am going to do is i will also look at the case of uniform circular motion with a couple of examples and we will explain the case of skidding of a car on a circular track and the role of friction there

so we start with the problem we start with the problem of multiple bodies connected by strings and we will take a very simple example we have a frictionless table on which we have a mass  $m_1$  a mass  $m_2$  the mass  $m_3$  these are connected by strings and at mass  $m_3$  the string is being pulled by a force of  $T_3$

so what we have been given is mass  $m_1$  which let us say is 10 kilograms mass  $m_2$  20 kilograms mass  $m_3$  30 kilograms all connected together by strings and here what is given to us is  $m_3$  is being pulled to the right by a force  $T_3$  is equal to 100 newton

so 100 newton force is applied to the block on the right and so all of them are moving it is a frictionless contact we have to find the axis

so what we have to find in this problem is find acceleration of the blocks and the force in the string connecting  $m_1$  and  $m_2$  and the string connecting  $m_2$  and  $m_3$  that means we have to find the force in this string and the force in this string and at the same time we have to find the acceleration of the blocks now if the strings are inextensible that means the lengths are constant and if the lengths are constant then the distance moved by block one two and three are same and what this gives us is acceleration of block one must be equal to acceleration of block two must be equal to acceleration of block three and this we can call is the kinematical constraint which we get on this multi body problem we have problem of three bodies

so actually there should be three accelerations but because they are connected by inextensible strings their accelerations are equal

so  $a_1$  is equal to  $a_2$  is equal to  $a_3$

so this is what kinematics tells us now you may think that this will be the case every time ah not today but in the next class we will see a problems where we have bodies connected by strings and where the accelerations may not be equal and ah today we will just consider a very simple example

so here all the three accelerations are equal

so now as we have seen to solve any problem we will draw the free body diagram

so lets start keep in mind this is our original system this force we have called this as  $T_3$  this is body one this is body two this is body three and this is a string this is also a string

so let's start with drawing the free body diagram i draw the free body diagram of body three on body three we have the force in the string on the right given by  $T_3$  to us then there is the weight of the body the normal reaction from the ground on the body at this contact there is no friction

so there is no horizontal force we only have the normal reaction and we have the force which this string applies let us call this as  $T_2$  which is now not known

so we have this is the free body diagram of body 3 and if i write this we look at this then in the y direction normal reaction and weight balance each other

so there is that is the equation we do not get anything on the x direction what we get is  $T_3$  minus  $T_2$  this is the net force in the x direction this must be equal to  $m_3$  times  $a_3$

so this is the equation which i get i first draw the free body diagram i write the equation now let us draw the free body diagram of body two on body two what we have is this is body two we have in fact i should put this as  $m_3 g$  we have the weight of the body two acting  $m_2 g$  this let me put it as  $n_3$  there is a normal reaction  $n_2$  now on body two the string pulls the body two

so the force on body two by the string is in the right direction we call it as  $t_2$  and there is a force which is the first string is applying we call this as  $t_1$  and from here when we write the equation of newton's law when we apply this in the x direction what we will get is  $t_2$  minus  $t_1$  is equal to  $m_2 a_2$  then we go to body 1 for body 1 this is body 1 we have the string force being applied here  $t_1$  and then we have of course  $n_1$  and  $m_1 g$  which are not relevant and this is the only force we have

so then what we have is we get our equation when we now in the x direction when we apply newton's law we get  $t_1$  is equal to  $m_1 a_1$

so therefore when we write the three equations we have  $t_3$  minus  $t_2$  is equal to  $m_3 a_3$   $t_2$  minus  $t_1$  is equal to  $m_2 a_2$  and  $t_1$  is equal to  $m_1 a_1$

so these are the three equations for the three bodies which we get now we use the kinematical constraint and we say we have shown  $a_1$  is equal to  $a_2$  is equal to  $a_3$  let us call this as  $a$

so therefore all these three are equal

so what we can do is let us add up all these equations when we add up all these equations we get  $t_3$   $t_2$  will cancel out  $t_1$  is will cancel out will be equal to  $m_1$  plus  $m_2$  plus  $m_3$  times  $a$  and since all these masses are given so therefore we can get the value of acceleration this will be equal to  $t_3$  divided by  $m_1$  plus  $m_2$  plus  $m_3$

so from here we will be able to get the value of acceleration  $a$  once we get the acceleration  $a$  we can go to this equation the first equation and

so we go to the first equation let's write this

so this implies we get  $a$  then we go to equation number one  $t_3$  minus  $t_2$  is equal to  $m_3$  times  $a$

so from this equation we can get the value of  $t_2$   $t_2$  will be equal to  $t_3$  minus  $m_3$  times  $a$  and then we can go to the first equation  $t_1$  we already know this is equal to  $f_1$  times  $a$

so therefore we can solve the value of  $t_1$   $t_2$  and  $a$  these are the three unknowns  $t_3$  was given to us there was one unknown acceleration

so we can solve a problem like this when we work out the numbers what we get is numbers acceleration  $a$  will turn out to be 5 by 3 meters per second square for the given values of  $m_1$   $m_2$  and  $m_3$  and  $t_1$  turns out to be equal to 10 times  $a$  and  $t_2$  turns out to be equal to thirty times  $a$  and  $t_3$  terms comes to be it works out to be equal to sixty times  $f$

so this is what we see also is that the tension in each string on the right keeps on reducing and this particular ah example is something like an engine pulling train compartments and this gives you the forces in the links between the various compartments of the train and what we will realize is if masses  $m_1$   $m_2$  and  $m_3$  are equal then you will be able to show  $t_3$  will be equal to 3 times  $m a$   $t_2$  will be equal to 2 times  $m a$  and  $t_1$  will be equal to  $m$  times  $a$

so this is how one can work out the force between compartments in a tray

so having seen this example let us now revisit the case of a body in uniform circular motion we have already seen example of this but let us once again recap this when a body is in circular motion that means it is moving in a circular track like this uniform motion means the velocity  $v$  has a constant

magnitude which we can write it as  $v$  and its circular motion that means it is moving in a path which is circular let the radius of the path be  $r$

so whenever we have a body which is moving like this then what we realize is that there is a component of acceleration which points towards the center so for a body to move in a circular path there will be a component of acceleration toward the center and this radial component of acceleration which we can call it this is equal to  $v^2 / r$

so even if the body is moving with a constant speed but the fact that it is at a curved path or a circular path has a it gives it a radial component of acceleration equal to  $v^2 / r$  and this acceleration has to be provided by some force of the body unless this force is there on the body it will not be able to move in a circular path

so let us take an example of what is called as a conical pendulum a conical pendulum suppose we have a string

so we have a string we have a body we have a string we connect it with a mass  $m$  a ball of mass  $m$  this is a string this is what we call as a pendulum now what we do is let us this was the initial position of the pendulum let us take it at an angle  $\theta$  and then we let this pendulum move in a circular path

so if this pendulum moves in its own plane this is what we call as a simple pendulum but in case of a conical pendulum what we do is let us say let me explain this again this is the pendulum this thing

so first we take this bob or the pendulum we make it move at an angle  $\theta$  and then it follows a circular path at this height

so for example if this length of the string is  $l$  and it is at an angle  $\theta$  then the conical pendulum

so this will be  $l \cos \theta$  this will be  $l \sin \theta$  this moves in a circle of radius  $r$  is equal to  $l \sin \theta$  and the height or the height of the pendulum from the plane of motion of the ball this is equal to  $l \cos \theta$  and

so this is what is referred to as a conical pendulum

so let us see the motion of a or uniform circular motion of a conical pendulum and let us try to analyze this dynamically

so therefore what we have as we have shown in the figure this is a pendulum this is a an angle  $\theta$  and this is traversing a circular path if i draw the free body diagram of the ball of the pendulum

so then i draw the ball what i have is its weight acting downwards and we have this ah force in the string which we call tension or represented by  $t$  at the angle of the string and this angle which it makes with the vertical is  $\theta$  so these are the only two forces acting on the ball of the pendulum that is the weight acting downwards and the string force  $t$  now because the pendulum as i have shown here is in a circular motion then we realize it has a radial acceleration component which is equal to  $v^2 / r$  and this component of acceleration in this case as i said earlier there has to be some force which has to provide this acceleration otherwise the body will not be able to move in a circular path and in this case the this acceleration is provided by the horizontal component of  $t$

so if we now write the if we write the equations here body is moving in a circular path

so therefore what we have is in the vertical direction if we call this as the  $z$  direction if we call it at the  $r$  direction now in the  $z$  direction we have  $t \cos \theta$  is the force by tension minus  $mg$  these are the forces and the body is not moving in the  $z$  direction at all

so acceleration in the  $z$  direction is zero

so the z direction newton's law gives us  $T \cos \theta - mg$  is equal to zero and in the radial direction we have only a single force which is equal to  $T \sin \theta$  and this must be equal to mass times acceleration in the radial direction

so this is equal to  $m \frac{v^2}{r}$

so we have these equations and from here what we get is if we look at first equation

so  $T \cos \theta - mg$  is equal to 0 and  $T \sin \theta$  is equal to  $m \frac{v^2}{r}$  and also we have shown if  $l$  and  $\theta$  are our two variables then  $r$  is equal to  $l \sin \theta$

so from here when we work this out what we get is the velocity  $T$  tension is equal to  $mg$  divided by  $\cos \theta$  and  $v^2$  is equal to  $g r \tan \theta$  or sorry  $v$  is equal to  $\sqrt{g r \tan \theta}$

so this is how we get if the ball has to move with the speed  $v$  then the angle  $\theta$  which will maintain will be given by this and  $r$  is  $l \sin \theta$  so we can convert things in terms of the variables we have

so we would like to work out the time period of the pendulum time period of the pendulum will be equal to the circular distance moved by the pendulum divided by the magnitude of the velocity or the speed

so therefore this will be equal to  $2\pi r$  divided by  $v$  and when we work this out this will be equal to  $2\pi r$  divided by  $v$   $v$  was  $\sqrt{g r \tan \theta}$  and when we put  $r$  is equal to  $l \sin \theta$  then what we get is that the time period will be equal to  $2\pi$  times  $\sqrt{\frac{l \cos \theta}{g}}$  and this gives us an interesting interesting fact that the time period of this conical pendulum is only a function of  $l \cos \theta$  and  $l \cos \theta$  as we have seen if this is the conical pendulum this is the angle  $l$  this is angle  $\theta$  this is  $l \cos \theta$  is nothing but the height of the pendulum

so if we have four or five conical pendulums rotating about the same base and if they have different lengths then if the time periods is same then they will be all in the same horizontal plane because  $l \cos \theta$  will be the same so that means the angles  $\theta$  will vary but they will all move in the same horizontal plane

so this is the conical pendulum now let us try to analyze about bodies moving on a circular track and we will assume that the body is moving with a constant speed

so as a let us say we have a car which is moving on a highway its first moving along a straight section and then it encounter it comes across a turn so at a turn the it goes in a turn it is a circular arc and when the body is moving in a circular arc then as we have seen there has to be a radial component of acceleration which is there now if the body is moving let us say this is the straight part of the track is moving along a straight part of the track with the constant speed

so then the acceleration on the body will be zero and no force will be required in that particular direction for the body to move but once so therefore let us say this is the body which we have this was moving so take this as the body it was moving along a straight path assuming if it is just moving along the straight path but once it comes on a curved path then there has to be some some external force which has to provide this radial component of the acceleration as it moves along the curved path and this radial component of the acceleration is what is provided by the friction and in this case we will assume that the friction force which is in the direction of the motion of the car that is in the tangential direction let us neglect that but just to provide this radial component of acceleration a friction force has to be there in the radial direction also and let us try to draw the

if this is the body moving in a circular track  
 so let me now show this as a in the figure on a plane  
 so we have a curved track on which a body is moving let us say the vertical direction is z this is r and  
 so now what i draw is i draw the free body diagram of the particle and i look at the r z plane  
 so in the z plane what we will have is we will have the normal reaction and we have the weight  
 so this is in a  
 so this z plane is perpendicular to the paper  
 so here z is coming out of the paper and i am looking at the free body diagram and when i draw the free body diagram this is the z direction which means this is the direction  
 so i am looking at a view of this paper perpendicular to the paper and towards the center in the r direction if this is the r direction what i will have is that there has to be a friction force which is acting on the wheels and when i now write my equations what i will get is  $n$  is equal to  $mg$  because there is no compo no acceleration in the z direction and the friction force has to be equal to  $m v^2$  upon  $r$  this is in the r direction  
 so therefore what we get is the friction force between the road and the particle in the r direction this is what provides the centripetal acceleration but we realize there is a limitation with the friction force what we know is friction force has a limiting value and maximum value of the friction force is equal to  $\mu_s$  times  $n$  and once the body starts to move then friction force is equal to  $\mu_k$  times  $n$  in the direction opposing the motion  
 so as long as we have friction is equal to  $m v^2$  by  $r$  now and we also know  $n$  is equal to  $m g$   
 so maximum value of friction force will be equal to  $\mu_s$  times  $n$  which will be equal to  $\mu_s$  times  $mg$  now if the particle moves along the circle with a large  $v$  or less  $r$  that means it travels the curve with a lower value of radius or with a large value of velocity then it is possible that the friction force or  $f_{max}$  is less than  $m v^2$  by  $r$  now if the maximum value or limiting value of friction is less than  $m v^2$  by  $r$  then what will happen is the once this value is attained the motion uniform circular motion circular motion will not be possible why will it not be possible because friction can have a maximum value of  $\mu_s$  times  $mg$  but this  $\mu_s$  times  $mg$  is  
 so high that is it has exceeded the value of  $\mu_s$  times  $mg$   $m v^2$  by  $r$  is greater than  $\mu_s$   
 so is greater than  $\mu_s$  times  $mg$   
 so for this  $m v^2$  upon  $r$  has to be greater than  $\mu_s$  times  $mg$  and if that happens then the body will start to move out because once this happens so this circular motion will not be possible and what will happen is  $\mu_s$  times  $mg$  will have the body starts to move such that  $r$  becomes large because that is the only force which friction can provide and  
 so because that is not there  
 so the acceleration is there in the opposite direction friction is not enough  
 so we have an acceleration in the opposite direction to slow this motion  
 so therefore  $r$  becomes large and this is what we term as skidding of the car  
 so the car starts to skid in a outward direction on the circle  
 so to prevent skidding therefore what can be done well normally what we will realize is skidding will happen it's possible when is on a surface where  $\mu$  is low

so that is why when we have icy surfaces then there is a possibility of vehicles skidding when they go along a curve and therefore to prevent skidding what should the driver do they should reduce  $v$  or increase  $r$  now if the road has a fixed curve then  $r$  cannot be changed then the only way to prevent skidding will be to reduce  $v$  and it is very effective because it goes like  $v^2$  upon  $r$

so when you drive and reduce  $v$  to reduce skidding this can be done now there is another thing which is done on highways to reduce skidding and this is what we do is the highway is tilted at an angle if we have a curve on the highway

so what we do is it is tilted at an angle and this is what we call as banking of the road

so the vehicle as it goes its this road is tilted at an angle  $\theta$  and it is higher on the outside and lower on the inside

so there is a slight angle is given to the road which is termed as banking and what is the advantage of banking what will happen now is the normal reaction is not vertical it is at an angle

so normal reaction now is at an angle and what if we look at this if we draw the free body diagram this is  $mg$  this is  $n$

so now what we have is  $mg$  is equal to  $n \cos \theta$  and a component of normal reaction  $n \sin \theta$  which is the component of normal reaction this is the one which can provide the centripetal acceleration

so a component of  $n$  this provides the acceleration in the  $r$  direction and assuming we have a case where friction force is  $0$  there is no friction then what we have is  $n \sin \theta$  is equal to  $mv^2$  upon  $r$  and  $n \cos \theta$  is equal to  $mg$

so from here we can work out and what we have is for a road which is perfectly banked that means we do not require any friction we can work out the angle of banking  $\theta$  for a well designed group and what we get is the same thing  $n$  is equal to  $mg$  upon  $\cos \theta$

so  $mg \tan \theta$  is equal to  $mv^2$  upon  $r$  and we get the same thing  $v^2$  square is equal to  $rg \tan \theta$  as we got in the case of a pendulum

so therefore we can work out the angle of banking the  $\tan \theta$  is equal to  $v^2$  square upon  $rg$  gives that angle of bank

so that if the car goes with this speed and the radius  $r$  the that will be designed

so that there will be no scaling and the normal reaction itself will provide the force for the centripetal acceleration now

so we have seen some of these problems of circular motion let us look at a briefly look at the topic of what happens when we have friction force on a body which is in contact with a fluid and by a fluid we mean it could be a liquid or a gas and the examples of this would be an aeroplane travelling in air or we could have a block this is a block moving on a table but instead of there is a layer of let us say oil between the block and the table

so in effect what we are trying to see is what is the effect of this contact force of the liquid or of the gas on the body what we have seen is when we see when the contact is between two solids

so let us first look at the case of Coulombic law of friction when the contact between two solids

so this body one in touch with body two then what we say is at the point of contact we have

so let us say I am drawing the free body diagram of body one on point of contact what I show is there is a force in the normal direction which I call

as  $n$  and a force in the tangential direction which i refer to as the force of friction this is what i do when i have contact between two solid bodies and whatever modeling tells us is that this friction force is less than or equal to  $\mu$  times  $n$  when the bodies do not move there is no relative motion then this friction force is less than  $\mu$  times  $n$  but when there is relative motion friction force is equal to  $\mu$  times  $n$

so that means the friction force is of is written as a product or as a as a directly related to some other force and that is what happens when the contact is there between two solids but when we have a solid in contact with the fluid

so we have let us say this plane and which is moving with the velocity  $v$  let us say the acceleration is zero and surrounding this is air so now the air will also exert some force on the on this body and the friction

so the force in the tangential direction which will say

so here now what we will have is let us say on this a force  $f$  is being applied on this body and

so that it is moving at a constant speed  $f$  the friction force due to air on this body and this friction force is a force which is opposing the velocity  $v$  we call this as a force equal to we represent it as a single force we call it as the drag force and the drag force we find drag force  $d$  is a function of the velocity  $v$  the body is moving at a velocity  $v$

so the drag force is a function of  $v$  and this is the difference between solid friction and fluid friction in solid friction when the contact was solid the friction force was proportional to the normal reaction which was a force and in case of a fluid friction the drag or the friction force which we have this is a function of velocity and not a function of force and what we find is that if the this drag force which we write if the body moves at very slow speeds then the drag force is proportional to  $v$  and if the body moves at high speeds then the drag force is proportional to  $v$  square well it could be its in general a function of  $v$  but this is how what we take it and for high speeds for bodies moving at high speeds the drag force sometimes is represented as half times  $c$  times  $\rho$  of the fluid times  $v$  square times the area

so we have a body which is moving like this in with the velocity  $v$  the drag force on this which is the force in the direction opposite to the velocity because of this surrounding fluid this will be half times  $c$  this  $c$  is a constant which we can which is dependent on the shape of the body  $\rho$  of the fluid is density of the surrounding fluid and in general this  $a$  is the frontal area of the body which means if we project the body on a plane the area will be given by  $a$

so for example if this is a sphere

so if the body is a sphere then the area  $a$  will be equal to  $\pi r^2$  where  $r$  is the radius of the sphere

so now let us take the case of a body which is falling in a fluid

so suppose we have a tube filled with fluid and this is falling in the fluid so here what we have is in this case if we say the drag force is equal to half into  $c$   $d$  in the  $\rho$   $f$  into  $v$  square times  $a$  now what is if i draw the free body diagram of the falling body then what i have is its weight is acting down and in this direction we have the drag force which is acting upwards now what will happen is as the body starts to fall initially it is at a zero velocity

so there is no drag

so because of the weight the body starts to accelerate

so therefore what we will have is that  $mg$  minus  $d$  will be equal to mass times acceleration of the body but slowly the velocity increases and as the velocity increases the drag force will increase

so as the drag force increases then what will happen is this acceleration will come down and eventually the acceleration will become equal to zero and this is what we call as the case of terminal velocity when the body starts to move with zero acceleration we call it as terminal velocity and when we in this case when we when the body has achieved terminal velocity then acceleration is equal to zero and what we will have is  $mg$  is equal to  $d$  and if we write the drag force as  $\frac{1}{2} c \rho v^2 a$

so from here what we get is the terminal velocity square is equal to  $\frac{2mg}{c \rho}$  this  $\rho$  is  $\rho$  of the fluid times the frontal area of the body

so this is how one can get the expression for the terminal velocity but if  $v_t$  has not been achieved then we still have  $mg$  minus  $c$  times  $\frac{1}{2} \rho f v^2 a$  is equal to mass times acceleration which is equal to  $m \frac{dv}{dt}$  and

so now if you have to find the expression of velocity as a function of time you have to take whole of this left hand side as a denominator take the  $dt$  on the other side and then integrate

so this of course all of you may not realize but this is how we do it but once if you have to find the expression for the terminal velocity then we can get it like this and now lets look at an example example of a rain drop of radius  $r$  is equal to 1.5 millimeter which is falling from cloud of height  $h$  is equal to lets say fifteen hundred meters its given to us that  $c$  is equal to zero point six density of water is equal to thousand kilogram per meter cube and the density of air is given as 1.2 kilogram per meter cube and we are we have to find the terminal velocity of the rain drop

so if we draw the free body diagram of the rain drop we have this  $mg$  we have this drag force and because we are talking of terminal velocity these two must be equal

so  $mg$  is equal to  $d$  which is equal to  $\frac{1}{2} c \rho f v_t^2 a$

so now for this particular thing lets work it out the  $m$  is equal to  $\rho$  of water that is the density of water times the volume of the drop volume of the drop will be  $\frac{4}{3} \pi r^3$   $m$  times  $g$  is equal to  $\frac{1}{2} c \rho f$  is given to us  $\rho f$  is given to us and we look at the area  $a$  area will be equal to  $\pi r^2$

so when we put both of these in this expression for  $mg$  is equal to this what we will get is  $v_t$  is equal to square root of  $\frac{8 r \rho_w g}{3 c \rho_a}$  and putting in these numbers what we will get is this velocity will be equal to seven point four meters per second we will put everything in s i unit that means will have to convert one point five millimeters to meters now we realize this answer is independent of  $h$  and had the rain drop what so we have this as this way had  $d$  been equal to 0 then falling a height of 1500 meters velocity would have been equal to root of  $2$  times  $g$  times 1500 which would have been of the order of something like 200 meters per second so it would have been a very large velocity whereas because of the effect of the drag force it becomes 7.4 meters per second and this tells us that and also what we realize is the terminal velocity is independent of the height of the cloud

so therefore whatever be the height of the cloud once the raindrop reaches 7.4 meters per second for these given conditions it will just continue to fall at the same velocity and that tells us why we are safe otherwise possibly all

these raindrops which come from very high heights will peers will cause a lot of damage on the surfaces now also related to this i think concept of the terminal velocity is this very famous experiment by galileo from the leaning tower of pisa when galileo talked of free fall and we probably discussed this when we talked about kinematics then what he said was that if you take a stone or if you take a feather or a light ball anybody and if you if you take them to any height and then they should reach ground at the same time if we drop them from a particular height they should reach ground at the same time and we realize that a stone when we actually do the if we go to the leaning tower of pisa and from the top we take a stone and we take a feather or we take a ping pong ball of the same volumes and if we drop them we will find the stone drops much faster as compared to the feather and the reasons for this now become obvious it is because of the drag force and as we have seen the terminal velocity goes like

so if the bodies have the same geometry then  $\rho$ ,  $f$ ,  $a$ ,  $c$  and  $2$  and  $g$  will be the same it will depend on the mass of the body and the terminal velocity will be achieved much higher for a body of a larger mass

so therefore if you take a ball of lead on a ball of wood the ball of lead will fall will reach the ground earlier and that is because of the effect of the drag force and actually now if you go to a lot of these science museums we have these experiments being done there where in vacuum you have a feather and a ball being dropped from the same height and because in the vacuum the row fluid the terminal velocity is not there there is no drag force because there is a since you have created a vacuum

so there is the fluid does not exert any friction on that you do find that whether you drop a stone or a feather from the same height you get they reach the ground at the same time

so

this is how the fluid friction therefore we have seen how this is to be accounted for in simple problems well of course it turns out when we will study

uh later on the concept of viscosity then this drag coefficient could be would be related  $c$  this is what we call as the drag coefficient and this is related to the fluid viscosity and the symbol typically used as  $\eta$

so this we will talk of in a later time when we talk about this

so what we have seen is we have looked at these problems where we have solved problems involving forces on bodies and what we have seen is that we are basically to solve these problems of mechanics we are using the equation  $f$  is equal to  $m a$  this is the vector equation we divide it into its scalar

components and we will say  $f_x$  is equal to mass times acceleration in the  $x$  direction  $f_y$  is equal to mass times acceleration in the  $y$  direction or  $f_r$  is equal to mass times acceleration in the radial direction and in the problems which we saw in one of the components but the  $y$  or the  $z$  component the acceleration was zero

so the force is balanced out and in the other direction we worked out  $f$  is equal to we applied this equation  $f$  is equal to  $m$  times  $a$  and solve the

problems the problems we have solved are reasonably simple in nature in another problem solving session which i will call i will take up ah some more complex problems where there are more bodies which are connected to each other there is a constraint of motion

so those type of problems we will do in that session but in terms of topics the next topic which we will do is here we have seen applying newton's law in the form  $f$  is equal to  $m a$  now what we can do is acceleration can be written as  $dv$  by  $dt$

so this we can either we can take this  $dt$  on the other side we get  $f dt$  is

equal to  $m$  times  $dv$  this will give us as you will see the concept of impulse of a force also the other thing is we have this acceleration we have seen we can write it as  $a = dv/dt$  and this we can write as  $dv/ds \times ds/dt$  which is  $v \times dv/ds$  and when we put it in this form this is where using this form we will get to what is called the work energy formulation so ah after the problem solving of involving this type of techniques where we use acceleration directly we will introduce this concept of what we call as the work done and the integral of  $v dv$  which will lead us to the concept of kinetic energy and we will look at work energy formulation and impulse momentum formulation of newton's law you