

in today's class we will be analyzing the various type of forces which act on bodies or particles and this we will see is the first step in solving problems in mechanics where we want to relate force to acceleration of the body so if you have to relate force to acceleration of the body first we should be very clear what the different type of forces are which act on the body but before we do that ah let me just ah go back to the last lecture where we considered action and reaction forces on bodies and what we showed was that newton's third law says that

so let us look at it newton's third law and this we will see will be very important when we analyze forces on bodies what newton's third law says is that if there are two bodies a body a and a body b if a exerts a force  $f_{ba}$  on body b then the body b exerts a force  $f_{ab}$  on body a where  $f_{ab}$  is equal to minus of  $f_{ba}$  one of these forces is called the action the other is called the reaction now to explain this a bit better because let us consider a case of a table on which a book is kept

so this table is on the surface on the ground and on the table we have a book so here if i analyze the forces which are acting on the book and we will see more detailed analysis of different type of forces when we continue with this lecture but if i look at the forces acting on the book then clearly what we have is there is a force due to earth on the book and this is what we refer to as the weight as we will see and let us call this as  $f_{be}$

so  $f_{be}$  is the force by which the earth is pulling the book towards itself and what we also find is that the table exerts a force on the book let us call this force as  $f_{bt}$   $f_{bt}$  is the force which the table will exert on the book and if the book is at rest if the book is not moving then these two forces have to be equal and opposite

so in fact this  $f_{bt}$  should be acting on the same line so actually i should show it in the same location at the same arrow so this is where  $f_{bt}$  x and then what we have is if because  $f_{be}$  and  $f_{bt}$  these are both the forces acting on the book they cancel each other that means they are equal and opposite and

so the book is at rest now the point which i want to make here is that  $f_{be}$  and  $f_{bt}$  do not constitute an action reaction pair why is it so the reason is that both  $f_{be}$  and  $f_{bt}$  they act on the same body which is the book whereas action and reaction pair are on two different bodies one body exerts a force on the other one of them is action and as a reaction to this or the other body will exert an equal and opposite force on the first one

so therefore if we analyze  $f_{be}$  is the force on the book by the earth so what is the reaction to this force the reaction to  $f_{be}$  will be is i should put equal is  $f_{eb}$  the force on the earth by the book so the earth or the book will exert an equal and opposite force on the earth and these two forces are equal and opposite but one acts on the book the other acts on the earth now you may ask a question if there is no other force on the book the book tends to fall down whereas what happens to the earth why the earth doesn't move and because of this force by the book and what we will see is that it will not move because the force on the earth relatively is very very small as compared to the gravitational force acting on the earth because of its attraction to the sun

so therefore the effect which the force of which the book causes on the earth is very very small and does not cause an appreciable effect on the earth and we will see this law of gravitational motion briefly today but the details will be seen a bit later and similar to this we also the second force which we showed was  $f_{bt}$  which is the force on the book by the table

so if we want to find the reaction of this will be  $f_{tb}$  the force on the table by the book which will be equal and opposite to this and of course all of these happen to be equal to weight of the book is just because of the conditions of this problem but nothing is moving

so this is what we have to be very clear when we talk of action and reaction that they are on two different bodies but not on the same body

so now let us try to see what the what are the various types of forces which act on a body or at least for the purposes of the immediate next two chapters we will consider each body as a particle

so on a body or a particle which are the various types of forces acting the first type of forces which act they are forces which act from a distance that means if there is a particle here a force will act due to some other body which is not touching the body

so and these forces they arise

so they arise out of interaction with the body two let us say this is body one where body one and body two are not in contact the bodies are not touching each other and but they exert a force on each other the first of these force is and the one which we will use in most mechanics problems is the force due to gravity and here we apply what is termed as this newton's law of gravitation and here we apply what is termed as this newton's law of gravitation in fact that's what it is called we used universal because it acts between any two masses

so what this law says is if we have a mass  $m_1$  and a mass  $m_2$  and they are separated by a distance  $r$  then let's say this is body a this is body b then the force on the body a due to body b is given by  $G \frac{m_1 m_2}{r^2}$  this is the magnitude of the force and the direction is from a to b the force on body a the first sub represents the body on which the force is acting

so force on body a due to body b will be given by  $G \frac{m_1 m_2}{r^2}$   $m_1$  is mass of body a  $m_2$  is mass of body b  $r$  is the distance between these two the details of this law will follow uh afterwards after we have completed in fact some of the studying mechanics and rotational mechanics let me just discuss what is relevant for our needs here now first of all when we look at this  $G$  is a constant which is valid all over the universe that's why the law is termed as universal gravitation and  $G$  is given by the value of this is found to be this was done using experiment  $6.67 \times 10^{-11}$  newtons meter square per kg square

so now this is the value of  $G$  when we look at the earth and let us say there is a mass  $m$  which is either on the surface of the earth or very close to surface of the earth

so first thing what we will do is what we realize is by this law of gravitation anybody which is on the surface of earth or close to the surface will experience an gravitational force due to earth and let's say

so now i am treating the earth as a sphere that the capital  $M$  is mass of earth  $r_e$  is the radius of earth and we look at a mass  $m$  which is either on the surface of the let's first look at it on surface of the earth

so and what i will do is let me call this as  $m_b$  let us call this as a body b whose mass is  $m_b$

so now force on the body b because of earth will be given by  $G \frac{M m_b}{r^2}$  times mass of the earth divided by  $r^2$  and this  $r$  if the body is kept on the surface of the earth then  $r$  will be equal to radius of earth if body is on surface of earth and at least for purposes of solutions of problems right now and understanding this even if the body is slightly away from the surface of the earth we can still assume  $r$  to be radius of the earth because if we

look at it radius of earth is six three seven zero kilometers which means it will be equal to six point three seven into  $10$  to the power of 6 meters so therefore even if the body is 1 meter or 2 meters above the surface of the earth we can safely assume  $r$  to be radius of the earth

so now what we get is  $f$  due to  $b$  times  $e$  will be equal to  $g m$  over  $r e$  square times mass of the body  $b$  now here capital  $g$  capital  $m$  and  $r e$  square they are all constants mass of the earth is equal to  $6$  into  $10$  to the power of 4 kgs so therefore once we put this in this constant  $g$  times  $m$  divided by  $r e$  square we can call it another constant and this is referred to so  $g$  times  $m$  divided by  $r e$  square for this we use a symbol small  $g$  and this is called the con gravitational constant of course for each planet the value of this gravitational constant will be different because capital  $m$  and  $r$  will be different for different planets

so here we concentrate on earth and once we work these numbers i have given you the value of  $g m$  and  $r e$  square then what we get is small  $g$  is equal to 9.81 meters per second square and so therefore now what we have is if there is any anything close to surface of the earth the force on the body  $b$  due to the earth can be written as  $m b$  times  $g$

so this will be the force which earth exerts on any body and this we also call as the weight of the body as i said for problems we will be considering right now we will assume  $r e$  is just ah the distance is very close to the earth so  $r$  will be taken as  $r e$  and force due to earth will be taken as  $m$  times  $g$  now for purposes of problem solution you may be told to take the value of  $g$  as  $10$  meters per second square or 9.8 meters per second square

so those sort of assumptions you'll have to see what is allowed to you and you work accordingly also what we will realize is as you move away from the surface of the earth  $r$  will change and

so will this force but these variations we will keep for the later chapter where we study gravitational constant and even if you go inside the surface of the earth then again  $r$  will become less than the radius of the earth but those variations we are not see assuming and for purposes of things right now we will assume  $g$  to be constant given by 9.81 meters per second square and the force on the body will be equal to mass times  $g$  now in this is one of the basic forces which acts from a distance there are two more forces which act from a distance the first of these are the electrostatic forces which act on two charges

so if there are two charges then the force between them is given by  $1$  by  $4 \pi$  epsilon naught  $q_1 q_2$  upon  $r$  square this is force due to  $q_1$  on  $q_2$  or due to  $q_2$  on  $q_1$  they will be equal and opposite and  $q_1$  and  $q_2$  are charges and details of this you will see when you do electrostatics but the forces between  $q_1$  and  $q_2$  if there are two charges they don't touch each other still they will exert a force on each other and here of course as we have discussed very early in the class the direction will depend on the type of charges they are it could be either attractive or repulsive

so this is another force which acts from a distance the third type of force which acts from a distance are electro magnetic forces and electromagnetic forces are given by if a charge is travelling in a magnetic field then the force of the charge is given by  $q$  by  $c$  times  $v$  cross  $b$  where  $b$  is the magnetic field intensity and  $v$  is the velocity

so these are again some forces the

so we have seen three basic forces which act from a distance gravity electrostatic forces and electromagnetic forces and at least when we do basic mechanics problem where electromagnetic forces or electrostatic forces are not

included are not important or can be neglected then we will have only gravity as the force which acts from a distance

so next

so these are forces which we have seen the forces which act between two bodies which are away from each other and once again we should realize action reaction pair will exist between the two bodies if a  $q_1$  charge exerts a force on another charge  $q_2$  then they will exert equal and opposite forces on each other and the same goes with gravitational forces and other things next let us look at contact forces and these forces if suppose i have a block which is lying on a table or on a surface or the ground there is a block then the block exerts a force on the table and the table exerts an equal and opposite force on the block and these forces we will analyze now

so when we have two bodies  $a$  and  $b$  in contact we have a force  $F_{ab}$  and a force  $F_{ba}$  now in general this force is in a general direction which means i have a body  $a$  in touch with body  $b$  if i try to analyze the body  $a$  due to the contact the force which the body  $b$  exerts on body  $a$  which i call it as  $F_{ab}$  its direction is a general direction which means depending on the other forces acting on body  $a$  this the direction and the motion of body  $a$  the direction of  $F_{ab}$  will be decided now what we do is that if we have two bodies in contact

so let us generalize this position let us make this is body  $a$  this is body  $b$  and they are in contact at this point

so what we do is we divide this general force  $F_{ab}$  in two components and the first component we say is the normal component which is in a direction which is normal to the contact and the other force which is there we call it as the tangential component

so the contact force between bodies  $a$  and  $b$  will be divided into two parts a normal component which is perpendicular to the two areas and a tangential component which is in the tangential direction

so this is the first thing which we do to a contact force of course we have not talked about what these contact forces are what the normal force is what the tangential force are but first thing we do is we divide these into two parts now from kinematics we know that if we look at the contact between these two bodies then the relative motion of  $a$  and  $b$  this is body  $a$  this is body  $b$  if the bodies have to move with respect to each other the velocity if contact has to be maintained then the velocity of  $a$  and  $b$  with respect to each other is along the tangential direction

so if this has to be maintained the velocity has to be along tangential direction why can't we have a velocity along the normal direction just think about it if the body  $a$  and  $b$  have a velocity in the normal direction which is not equal then what will happen either the body  $a$  will pierce into body  $b$  or the two bodies will separate away from each other that means in one case the bodies will there will be no longer a point contact the bodies will start deforming which we are not considering and in the other case the bodies will start to move away from each other and there will be no contact

so the point which we are saying that the body's contact has to be maintained will no longer be there and

so there will be no force

so therefore when the bodies have to be in contact the relative motion between  $a$  and  $b$  has to be only along the tangential direction

so if we have a contact force between two bodies  $a$  and  $b$  it acts in a general direction we divide it into two components

so lets once again go back to the old example this is body  $a$  and this is let me just show if it is in touch with body  $b$  contact with body  $b$  then when i

look at the body a there will be force due to body b which is the earth and we divide it into two components the component which is normal to the surface we call it as  $n$  the normal reaction and the second component which we have

so that means let me just show it again this is body a due to body b the force on a due to body b is in some general direction we divide this into two components we resolve this  $f_{a/b}$  in a component which is perpendicular to the contact we call it as the normal reaction and the second component will be the tangential component and when the bodies are both the touching surfaces are solids then we have a special name we call it as the frictional force between the two bodies

so the tangential component is referred to of contact force this is referred to as the force of friction now force of friction could exist even if the body is in contact let us say with air or with water then there is a tangential component which will be a component called the frictional force due to air or water but there is a fundamental difference when we have the force of friction when contacting bodies are solids both of them are solids or we could have contact between a solid and a liquid or a gas and lets first look at the case when we have when both the contacting bodies are solids

so this is what we call generally referred to as force of friction

so if the contact is between solid and a liquid or a gas it's called the force due to fluid friction and the basic way we uh we write or we write the reaction relation between this force they will be different

so first let us look at the force of friction between two solid bodies

so now when we say friction two things are automatically implied the first thing is that is a contact force and secondly this is a force in the tangential direction these two things are automatically there and now let

us look at contact between two bodies two solid bodies and first we look at the kinematics of it before we

so we have a body a we have a body b now let the velocity of body a  $v_a$  and the velocity of body b

so velocity of body a is  $v_a$  and the velocity of body b is  $v_b$  now this could be and these are both as we say they are the tangential components of the velocities the normal components as we have discussed have to be equal if the bodies have to stay in contact

so we have these two velocities now at the contact if  $v_a$  is equal to  $v_b$  and actually what i should put is comma t which shows that it is a tangential component if these are equal at the given time t and also at the next time which i can represent by t plus or at the next instant then what we have is this condition is said to be no slip because the two bodies are not slipping with respect to each other as an example we see let us say this pen is lying on the table and if i look at the contact point of the pen and the contact point on the ground on on the sheet there the velocity of both of these are equal to 0 and they are 0 at this time they are 0 at the next time

so therefore  $v_a$  is equal to  $v_b$  and they happen to be 0

so and they are equal now if this whole table is moving with some other speed  $v_t$  but these two are not slipping with respect to each other then once again what we will have is  $v_a$  will be equal to  $v_b$  but both of them will not be equal to zero they will be equal to velocity of the table but still it is a condition of no slip

so slip is when we have movement of body one with respect to body two

so this condition when velocities are equal at the of the contact point at this time and at the next time this is called no slip now the second condition which obviously if there is no slip there should be something called slip and

what slip means is that at the time of consideration at the time  $t$  when you are observing the two bodies  $v_a t$  is not equal to  $v_b t$  and now let me change my body i put this duster or this block here now when i look at this if suppose i apply a force and this duster is moving now when i look at it point a which is on the duster has a velocity whereas the point on the ground has zero velocity

so  $v_a$  is not equal to  $v_b$  and when this is moving this is called slip so we have no slip and slip but in between these two we have a third condition which is what we call as impending slip and what impending slip implies is that at time  $t$   $v_a$  is equal to  $v_b$  let's just write this again for impending slip  $v_a$  tangential is equal to  $v_b$  tangential at time  $t$  but if we have the same conditions on the problem then at time at the next instant  $v_a$  will not be equal to  $v_b$  that means the body is just about to move and that condition is referred to as impending slip and once again if i put this duster here on the table this is right now it is a condition of no slip i slowly apply a force and i now i am applying the force you may see but it is not moving so it's still no slip but then when i increase the force it starts to move so just at the point when this starts to move is what is the condition of impending slip just before it starts moving once it starts to move we have slip

so these are the three kinematic states of contact a state of slip a state of no slip and a state of impending slip and sometime the slip could be replaced by the word slide

so now what has this got to do with friction and we have when two bodies are in contact we have what are come termed as coulomb's law of friction now what this law says is that when two bodies are in contact then the tangential force between these two bodies will be such that it tries to oppose the relative motion between these bodies and this tangential force which ah tries to oppose the relative motion between the two bodies this tangential force is what we call as the frictional force or the force of friction now so let's once again get back to this duster which is kept here let me invert it and

so now when this duster is kept on the block we say there is a contact and if there is a tangential force it will try to stop the relative motion of this on the other body now when no other force is being applied on this duster that means it has two forces it has a force due to the earth which is the weight of the duster and the other force is the contact force which will have two components a normal reaction and a friction now what we see is because the earth's force acts directly toward the center of the earth which means it acts in a vertical direction and because the body is not moving

so the contact force also has to be just opposing this force

so it will be just a normal force and force of friction on this will be zero

now what we do is we try to we i apply a small force i am applying this right now i apply a small force the body does not move now the body is not moving that means that the net horizontal force on this body must be equal to zero now i have applied a small force with my finger

so that force has to be balanced by something now that force is in the direction as i have shown here from right to left i'm applying this force with my finger as i've shown

so that means on the duster there has to be a force left to right which opposes the motion of this duster and that is the frictional force and this frictional force of course is in addition to the normal reaction which is balancing the weight

so because this body is in equilibrium sum of forces on this must be equal to

zero

so when i apply a small force the body doesn't move that means a friction force is automatically acting on the tangential surface which opposes the motion

so what we see is that this frictional force is a self adjusting force and it tries to oppose the motion now lets get back to this and what we see is now i apply a small force i slowly increase this force as i increase the force i see that the duster starts to move

so once it is moving that means it was at rest it starts to move that means its acceleration is not zero

so what we have is that this duster if i look at the kinematic state and as i increase the force

so we have increasing the horizontal force on the duster and let me show it with a small figure

so this is the duster i put a small force  $f$  this is does not move and what this means is that this contact force or friction force let me put it as small  $f$  this is the friction force  $f$  is equal to  $f$  in the  $f$  the two directions are opposite and of course if we go back to our law of action and reaction they do not constitute an action and reaction pair they are acting on the same body but

so these two forces are equal but what we see is as capital  $f$  increases we reach a stage where the duster is about to move

so i increase  $f$  i show it by a bigger arrow and i have a frictional force these two are still equal and this is just about to move now at this stage when just about to move this is what we have is the state of impending slip in the earlier case this was a state of no slip and then there is impending slip and suppose i increase  $f$  further then the duster starts to move

so that means there is an acceleration in this direction and what coulomb did was what coulomb got to us and coulombs laws what they say is that when we have impending slip that means the body is just about to move then the force of friction is equal to a constant  $\mu_s$  times  $n$  where  $n$  is the normal force or normal reaction on the body

so when we have a case of impending slip friction is directly proportional to the normal reaction and the constant of proportionality is given by  $\mu_s$  and this is called the coefficient of static friction

so now i go back to this duster let me draw all the forces earlier i just showed only the tangential forces on the duster

so we have this force  $f$  and this is a case of let me say impending slip we have the frictional force but then in addition to this we have the weight of the duster which is acting down and there is a normal reaction which is because of the ground on the duster

so now in what coulomb's law tells us is for impending slip  $f$  is equal to a constant times  $n$  and if the body is not moving in the vertical direction a force balance will give us  $n$  is equal to  $mg$  which we will see in a while when or maybe in the next class when we solve problems

so for impending slip the friction force is given by  $\mu_s$  times  $n$  now what happens when we have slip or no slip what coulomb found was that when we have slip then the force of friction is given by another coefficient  $\mu_k$  times  $n$

so therefore again force of once the body starts to move frictional force is still equal to is proportional to the normal reaction but it is given as  $\mu_k$  times  $n$  where  $\mu_k$  is the coefficient of kinetic friction  $n$  is still the normal reaction now ah when we have no slip then what we see is  $f$  is less than  $\mu_s n$  because friction is a self adjusting force

so it is in and for the case of no slip friction we do not have a direct relation or proportionality between friction force and the normal reaction all we can say is that the maximum value of friction force till we start to have slip will be equal to  $\mu_s n$  once

so friction force when we have this duster again we go back to this when i apply a small force if the force is less than  $\mu_s n$  there is no movement and when i increase it when it becomes equal to  $\mu_s n$  it will start to move and after that the force of friction will be given by  $\mu_k$  times  $n$  now few words about  $\mu_k$  and  $\mu_s$  generally what we find is  $\mu_k$  is less than  $\mu_s$  and the reason for that is that why does the friction force appear when we have these two bodies in contact then in the contact there is some sort of addition between the two bodies they tend to touch each other

so therefore there is a resistance to movement to relative movement between the two bodies and that is what causes the friction but once the body starts to move then the relative addition force goes down slightly because the body is already moving when the body is not moving this addition is stronger so that is why  $\mu_k$  is less than  $\mu_s$  but in some cases you may find  $\mu_k$  is equal to  $\mu_s$  also

so now what coulomb also found was that  $\mu_k$  and  $\mu_s$  they are independent of the relative velocity of the two bodies in contact and this is valid if the velocities are small if the velocities are large then they could be a function of velocity but for the cases which will consider will assume  $\mu_k$  and  $\mu_s$  are independent of relative velocities in contact and they depend on the surfaces of contact

so on the material of the surface of contact if we have let us say cemented floor or glass then we know that it is much easier to move a body on glass than on a cemented floor

so value of  $\mu$  will be less when we have contact with glass as compared to that with the cemented floor

so they depend on the surfaces of contact but for the same surface of contact  $\mu$  will be constant if we have two bodies of same material which are made then and both the contact materials have are of the same thing then we will have the value of  $\mu$  and  $\mu_s$  will be constant

so this will depend on the pair of surfaces and between each pair you will have a value of  $\mu_k$  and  $\mu_s$  now what we have seen here we have seen this for a single for a particle or for a block when we normally a lot of problems will be solving will deal with blocks and the block moves like one single body and move all the points it just is in a state of what we call translation where the entire block moves with the same velocity and in these cases we will find that when we look at bodies in translation then the block could might as well be a single particle shown by a dot

so when we consider forces like this we will consider forces on the on this acting at the same point but when we talk of rotation later then the relative the point where the forces are acting will also become important and in that context we can see that when we talk of the normal reaction on a block our tendency is to show this normal reaction acting at the center while this may be true for many cases but as we will see when we go to rotational equilibrium its possible that the normal reaction does not act at the center but it acts at some other point somewhere in the contact zone of the body and this when we do rotational equilibrium we will have to be careful about right now when we are talking of particles we just show we are only doing a force balance will not do a moment balance

so therefore equality of forces will be of importance

so we will talk of forces in the x direction forces in the y direction and

the net resultant of these must be equal to mass times acceleration in the respective directions and that is what we will see in the next class but before that

so we let just we have seen the law of friction and if i recapitulate if we look at the force of friction this will be less than  $\mu_s n$  for the case of no slip it will be equal to  $\mu_s n$  for impending slip and is equal to  $\mu_k n$  if there is slip one of the very common mistakes which students tend to make is that wherever they see friction they just put  $f$  is equal to  $\mu n$  and that is wrong we have to first ensure if there is a case of impending slip or slip only then we can put  $f$  is equal to  $\mu n$  if it is a case of no slip then friction will be an unknown force in the problem which has no direct relation to normal reaction except that it has to be less than  $\mu_s n$  but you cannot equate friction that if you know the values of  $\mu$  and you cannot blindly put  $f$  is equal to  $\mu n$  because if it is a case of no slip then it will be wrong if it is a case of impending slip or slip then we will put  $f$  is equal to  $\mu n$  and also you will realize when we solve the problems when you put  $f$  is equal to  $\mu_s n$  or  $\mu_k n$  you have to put it along with the right direction and the right direction of the frictional force let see that this has to oppose the relative slip on the body in question

so let's see i talk of the block and let us say this block is moving with a speed of five meters per second and this is on ground and the ground is at rest

so now lets say point a is on the block point b is on the ground velocity of point a is equal to  $v_a$  velocity of b is equal to zero i so velocity of a with respect to b is equal to  $v_a - v_b$  which is equal to five times i

so the relative velocity is in the i direction if that is

so then friction on body a because the relative velocity is in of body a with respect to b the contact point is in the i direction the friction force on body a is in the minus i direction and because now in this case because the friction force is in minus i direction and is it equal to  $\mu n$  or is it not equal to  $\mu n$  what can you say think about this this is a case of what is it a case of impending slip no slip or slip clearly this is a case of slip because  $v_a$  is not equal to  $v_b$

so therefore in this case friction force will be equal to  $\mu_k$  times  $n$  and this will be in the minus i direction

so now when i look at body b for the same example if i look at this is body b now on body b the friction force will be in the plus i direction how do i get this well there are two ways of doing this one is i can look at the action reaction pair friction on body a is in minus i direction

so the it will exert an opposite force in the tangential direction on body b

so therefore on body b the frictional force will be in the plus i direction or the other way i can look at is the relative velocity of b with respect to a now  $v_b$  is equal to 0  $v_a$  is equal to 5 phi

so  $v_b - v_a$  this is equal to minus pi phi

so because this relative velocity is in the minus i direction the force of friction on body b will be in the plus i direction and this is something which you should understand and get things very clear about

so this is how one works out the direction now maybe we can take one or two more examples here we have this block this is travelling with five meters per second and this is on an elevator and the elevator is also travelling with five meter per second and what we find is the acceleration of block this is a this is b acceleration of a if it is two meters per second square in the y direction and acceleration of b is also equal to two meters per second square

in the  $i$  direction now here if we want to analyze is this a case of slip no slip or impending slip then what we find is velocity of  $a$  with respect to  $b$  this is equal to five minus five so this is equal to zero and if i look at acceleration of  $a$  with respect to  $b$  this again is  $2 - 2$  which is equal to  $0$ . so since both velocity and accelerations are equal at the next instant also  $v$  and  $v_b$  will be equal so therefore clearly this is a case of no slip and here when i write the friction force on body  $a$  all what i can say is friction force will be less than  $\mu$  times  $n$  and i can't even determine its direction till i know the other things which are happening on the body and i'll have to look at the other forces on the body to be able to find the direction but one thing you'll realize when we have a case of no slip then you just show friction as a force in either the plus  $x$  direction or the minus  $x$  direction and the correct direction of it will come out from the answer if you get the answer as minus that means the direction you had assumed was wrong so for case of no slip you can get away by putting either in the plus direction or in the minus direction but if it is a case of impending slip or slip then you have to show the right direction of the friction force on the body now in this example how would an impending slip occur suppose if the acceleration of  $b$  was  $3$  meters per second square so then this would have become a case of impending slip so let us just do this this is  $a$  this is on body  $b$  this is  $5$  meters per second body  $b$  is also moving with  $5$  meters per second acceleration is  $2$  meters per second square i acceleration of  $b$  is  $3$  meters per second square i so now when we see slip  $v_a$  is equal to  $v_b$  so this means not slipping but when i look at  $a_a - a_b$  this is acceleration of  $a$  with respect to  $b$  this is equal to  $2 - 3$  i so this is equal to minus  $i$  so that means we have a case of impending slip and the direction of impending slip on body  $a$  is in the minus  $i$  direction so therefore the friction force on body  $a$  will be in the plus  $i$  direction so friction force when i draw body  $a$  the friction force will be in the plus  $i$  direction and this will be equal to  $\mu_s$  times  $n$  because this is a case of impending slip so these sort of considerations we have to keep in mind when we solve problems of friction so in today's class what we have seen we have seen two things first we saw forces when forces on bodies which act from a distance in fact i have not used the name sometimes when we go for advanced courses we call them as body forces and the we saw the force of gravity which will be of importance to us and the main takeaway for us is that if there is a mass  $m$  close to the surface of earth on surf or on surface of earth the force which the earth will exert on that mass is equal to  $m$  times  $g$  which will act in the vertical direction that is toward the center of the earth so that is one thing and we also saw electromagnetic and electrostatic forces which could act from a distance and after that we looked at contact forces we started the discussion and we talked of normal reaction and friction and in detail we have seen how frictional forces act on bodies how they are related to the normal reaction in the next class we will look at some more forces in particular the force do when a string is tied to a body and when a spring is attached to a body and after which we will move to application of newton's second law on a problem so that we can relate the forces to acceleration thank you you