so welcome all of you to this set of lectures which correspond to chapter 8 of your class 11 cbse book

so the student should know what chapter 8 is that is the chapter on gravitation newton's universal law of gravitation

so in the next few lectures we are going to explore and explain various aspects of gravitation as a phenomenon and how newton's law encompasses a vast variety of phenomena starting from a falling apple freely falling body in a gravitational field tidal phenomena planetary motion and even interaction between galaxies and of course artificial satellites this is one of the most important topics for a physics student because this is the first instance of a situation where a fundamental law was discovered a law governing the properties of all kinds of matter was discovered and this had far reaching implications on our understanding of nature of the very nature of physics and our approach to understanding what our universe is and because of that it also had a far reaching implication on philosophy you will not be exposed to all of them in these lectures for that matter even in your classroom but it is good to remember that discovery of law of gravitation is one of the hallmarks one of the high points of the human civilization

so with this brief introduction let me get to work

so what i am going to do is not to start straight away with gravitation because the very formulation of gravitational law was preceded by major developments in our understanding of the concept of a frame of reference the concept of a free particle the concept of a force the concept of a work so on and

so forth and i know that both in your classroom and in these very lectures you have been exposed in great detail to all these concepts but it does not harm us to repeat these concepts even if it is done very briefly because that will prepare us to understand and appreciate what whatever we are going to study with our week gravitation

so let me first give an outline of what all i am going to cover in this course the first thing that we shall do is to revise the concepts

so what are the concepts that we are going to revise i am going to revise the concept of force which is fundamental because we say gravitational force electromagnetic force so on and

so forth then comes the concept of work followed by two important concepts kinetic and potential energies which leads to conservation of energy

so this is what we broadly call as mechanics there are a few more things which are associated with it namely conservation of momentum and conservation of angular momentum which will also be briefly summarized revised by me before i get into a discussion of gravitation before we start discussing gravitation it is good for us to remember and realize that gravitation is one of the four fundamental forces

so we have the concept of a fundamental force we have the concept of a derived force or an effective force

so it is remarkable that one of the first forces to be discovered was actually a fundamental force therefore what we shall do is to very very briefly describe the four fundamental forces and i have listed them here gravitation electromagnetism nuclear forces and weak interactions in some way or the other you will be exposed to all the four of them gravitation of course will be described in these lectures which will be taught in great detail in your class electromagnetism of course covers a major part of your syllabus in the 12 standard you will also study a bit of nuclear forces fission fusion etcetera and even weak interactions you study in the chapter of beta tk

radioactivity although you may not be told that weak   interactions are responsible

so in some sense you are going to be exposed to all these topics   even if these forces are not explicitly mentioned especially the weak interactions therefore what i will do is to spend some time discussing them after revising the concepts once we do that we can get to the study of gravitation proper so the first phenomenon that we have to study is the problem of freely falling body in the   earth's gravitational field and that is the famous galilean law so there is a legend that aristotle   believed or aristotle propagated that later objects move up and heavier objects come down   of course such a thing may happen if i put a piece of paper it comes down much more slowly   than a heavy object like a stone but galileo is credited to have done an experiment from the   leaning tower of pisa where he dropped two objects let us say gold and tin or a stone and a block of   lead and they fell with the same acceleration and they reached the ground at the same time   this experiment is very very important for us because it brings out a far reaching concept   in fact a very intriguing concept called the equivalence of inertial and gravitational mass   this is a peculiarity of gravitation so we are going to use galileo's law to motivate not only   the universal law of gravitation but also the equivalence of inertia and gravitational mass this equivalence seems very innocuous very simple and kind of an accident but this was the basis of   einstein's generalization of gravity where he went beyond newton's theory and gave general theory of   relativity you may have heard of it black holes space time curved and all that

so all of it comes   from this equivalence principle to start with before i straight away go to gravitation again   what we now do is to look at celestial phenomena celestial is what happens in the sky

so what is important for us is to know how the ancient astronomers all over the world   babylonians greeks chinese indians they were able to determine distances and time periods of objects   in the sky

so you know that eclipses are very precisely predicted the motion of constellations   is known the period of the sun is known very well the period of the moon is known even the size of   the moon the sun and the earth were estimated to quite a good approximation therefore before we   embark on a study of gravitation it is important for us to know how even in the absence of   loss of physics people were able to estimate measure

so to say

so we will start with that   and then again of course we have the great tradition of astronomical tables in the greek   and the indian traditions especially and we will describe how kepler was able to analyze the data   and give the loss of planetary motion that is very very important there are three laws of   planetary motion

so that is something that we need newton was extraordinarily fortunate to have been   in the position of kepler's law kepler himself was fortunate that tycho brahe actually recorded   the motion of the celestial bodies very precisely of course it goes back to very very ancient times   of the period of ptolemy and aryabhatta newton was in possession of all these things all these data   and he knew galileo's law of a freely falling body combining the two the earthly phenomenon   and the celestial phenomena newton was able to formulate universal law of gravitation that is   why it is called universal there is no body in this universe which does not experience   a gravitational force which does not exert a gravitational force on the other bodies this   is a property which is not shared by other forces so after enunciating newton's law of gravitation   since we are looking at

celestial phenomena we will look at two phenomena one of course is the motion of the earth around the sun and the motion of the planets around the sun we will make a simplified approximation that the orbits are all circular for the sake of simplicity the orbits of course are not entirely circular but it does not matter then we are also going to discuss the motion of the moon around the earth which is what you have in your syllabus now after discussing these two phenomena actually for discussing these two phenomena we will need basic information like mass of the earth and the shape of the earth we come back to the terrestrial gravity and that is the famous acceleration due to gravity many many problems which you people have solved so here of course the distance of an object from the surface of the earth is very very small compared to the radius of the earth therefore g is taken to be a constant most of the time 10 in si units 9.8 let us say but actually g varies as you move away from the surface of the earth as you move on variant points of the various points on the surface of the earth

so we will discuss that there are two contributions that are going to come for the variation of g the acceleration due to gravity one is not one is the inexact spherical shape earth is not an exact sphere but it is what is called as a geoid it is flattened at the poles and is bulging at the equator therefore my acceleration due to gravity changes and the other phenomena which you are all familiar with is that the earth not only revolves around the sun but it also rotates about this axis which is inclined at an angle 23 and a half degrees which is very very important because that is responsible for the seasons

so that also causes variation in acceleration due to gravity that is an effective acceleration due to gravity we have to worry about that we will discuss that

so in doing that we will also spend some time to understand the distinction between mass and weight newton's fundamental law is formulated in terms of mass what we measure in earth's gravitational field is weight they are not the same weight can vary archimedes principle says that weight can change but the mass cannot change

so we will discuss that after that we move on to discuss satellite motion of course moon is a satellite for the earth but today we have lot of artificial satellites we are launching a large number of satellites many countries are launching a large number of satellites and india our country is a very very major player in that

so you me people might have watched on the tv or reading the newspaper that in a remarkable feat our indian space research organization launched more than 100 satellites in one shot over a period of 10 minutes it was done this problem actually involves very fascinating ideas including conservation of momentum conservation of angular momentum and what their masses should be so on and

so forth i will try to spend some time on them and then of course we have the famous geostationary orbits which fixes the distance we will also discuss them in studying all this i will also be working out i will be trying to work out a large number of toy models involving gravitational force conservation of momentum conservation of angle or momentum inelastic collisions breakup of masses and things like that

so that not only will you be comfortable with the concepts but you will also become more proficient with the technicalities on how to formulate and how to solve problems so this is essentially the outline of the course

so before i proceed it is important for us to know what exactly is the impact of gravitation i told you that it is one of the fundamental forces i will

define what fundamental is   in a while maybe one of the future slides   but in order to understand its scope you should know that gravitation describes almost everything   beyond the earth including terrestrial phenomena

so terrestrial means whatever happens on the earth   falling body etcetera etcetera then it describes planetary motion

so if you look at our solar   system it describes planetary motion and by the way in the terrestrial we should also include the   phenomena of tides newton was the first person to recognize this and he actually computed the   tides and we can work out a small problem involving the tides   as to how there is a difference in the height in fact it is quite interesting because although the moon's gravitational field is much much weaker compared to that of the sun after all the earth goes around the sun and not around the moon the moon goes around the earth   but still when it comes to tidal phenomena the gravitational field of the moon is much   more important than the gravitational field of the sun

so it is a very good thing to discuss   although i will not be discussing them in great detail gravitation is responsible for the dynamics   of stars for example we know sun is producing enormous energy because of nuclear fusion so the world's original tokamak the fusion reactor were all built inside the deep center of the   stars that is how the stars are shining now how is it that such large temperatures and such   fusion you know the protons and the neutrons can come very close to each other in spite   of the coulomb repulsion it is because of the gravitational field then we have the   galactic dynamics you actually have also have the interaction between various stars   galactic dynamics involves how galaxies are held together or how one galaxy can interact   with the other galaxy and ultimately we have the large scale structure for the universe

so if you imagine that we know today about 10 to the power of 10 or 10 to the power of 12 galaxies   that is our universe every galaxy is like a point in the universe then the interaction between the   galaxies and how the way our nature behaves is actually described by loss of gravitation   not entirely newton's laws but also its improvement its generalization given by einstein but still the foundations were all laid by newton

so this is something that we have to remember

so like they say the all the world is a stage for gravitation all the world is a stage

so this must be a good enough introduction and motivation for us to start with gravitation

so let us start with a brief review of the basic dynamical concepts i will not spend any time on the kinematical concepts

so you have kinematics and you have dynamics   kinematics involves the concept of position velocity acceleration etcetera etcetera i will   assume that two people are familiar with that i will also assume the two people are familiar with   the fact that velocity is a derivative of position acceleration is the second derivative of position   or the derivative of velocity i am not going to discuss that

so given that we have to go to   dynamics

so what are the three important concepts that we are going to discuss we first describe   galilean law of inertia which gives rise to the concept of an inertial frame which newton encoded   in his formulation of dynamics as the first law

so the first law of motion is actually due to   galileo the second law of course which is fundamental which is extraordinarily important   is the action of an applied force on a body here the emphasis is on the word applied

so we will describe that and the third law is the famous action and reaction which actually is a version of what we call as the conservation of momentum so we will formulate it in that particular way because we are going to use all the three of them i will not be discussing the conservation of angle or momentum at this particular point it is beyond the course

so we will simply state the principle whenever required and we will make use of them

so we have to start with the concept of forces and inertial frames inertial frame is the most important concept and i know and i am sure that a fair amount of time has been spent on that concept in the earlier lectures in iit palm so please go back to those lectures listen to them and again pay attention to these lectures two important names that crop up when we speak of forces and inertial frames or that of newton and of mark mark questioned the concept of an inertial frame the importance of an inertial frame i am not going to discuss that at this particular point but basically as far as practical purposes are concerned the foundations for the concept of inertial frame were laid down by galileo and newton this is not to be little what mark did mark raised many many fundamental questions which actually motivated einstein to develop his generality of relativity in fact he called it the mark principle although ultimately his theory was not in agreement with the mark principle okay so let us start with a few concepts which you people are all familiar with and that is motion of a body

so here when i speak of the motion of a body it is good to assume that it is a point particle although the conclusions are independent of that because it simplifies our discussions

so now let us start with the basics of basics what do we mean by saying that a body is moving

so there is what is called as kinematic relativity kinematic relativity

so what does it say it says that if there are two particles a and b if b is moving with a velocity v with respect to a then from the viewpoint of b a is moving with a velocity minus v there is no question about that similarly if b is moving with an acceleration a with respect to b my a will be moving with an acceleration minus a with respect to b

so we call it relative motion relative acceleration and this is perfectly symmetric between a and b it does not involve any concept of dynamics now why is it important for us we could have simply said all motion is relative but we know that whenever we want to set a body in motion that is very very important for us

so imagine there is this table and there is this block in order to set this body in motion we will have to apply a force or imagine there is this road and there is this car going with a speed v if you want to change its speed or if you want to change its velocity then you have to apply breaks again a force is required

so whenever we want to change the state of motion of a body

so change of state of motion of a body requires force

so in the first example the body was at rest in the second example the body was in a uniform motion

so what is the problem between the statement that all motion is relative and i require the force we can look at a very simple example of merry-go-round all of you have sat on it in a merry-go-round you are going round and round about the central pole but if you look around it would appear as if the rest of the world goes around you as if rest of the world rotates now whenever there is a rotation there is a continuous change in velocity even if there is no continuous change in the speed because all of you know that my acceleration is

like v squared by   r

so there is an acceleration with the variation of distance and the direction of speed itself   is changing at any given distance

so the state of motion of the rest of the world is changing   but common sense our own appreciation of what we understand when we look around us tells us that   the force is acting on us whoever is sitting on the merry-go-round but not on the rest of the world

so in other words kinematically although all motion may be relative   but the change of motion caused by the force can be properly described only in sun frames

so change of motion caused by forces requires identification of special frames and this is not an easy task for example if you look at the   greek astronomy and the way it was formulated by aristotle and later during the medieval pair   people assume that the earth is the center of the universe and all the celestial bodies go around the earth

so earth was considered to be stationary   and all the celestial bodies were supposed to go around now if you forget the planets asteroids   meteorites and even the sun but you look at the distant stars fixed stars then you will see that they all rise at the same time and set at the same time   irrespective of where they are

so if you make a statement that   their state of motion should be because of the force we would have to say that they are all   acted upon by forces such that they all move with a constant angular velocity   which is me some kind of a conspiracy of nature

so this is something which actually   worried many many astronomers and one of them was a great indian astronomer ayo bhutta   who argued that a simpler description would be to say that the stars are fixed they are   not moving at all it is actually the earth that is rotating about its axis   the minute you assume that it is the earth rotating about its axis   then the circular motion of the stars with a constant period irrespective of how far they   are acquires a natural description of course we are not saying that aryabhatta knew what he was   saying entirely because the concept of a force was not very clear at that particular point   but we already see that there is a hint for such a argument to make and   the person who actually formulated this concept in a very precise manner is galileo

so let me describe that i have summarized that in a single line   in this slide the first law for free particles and what does the summary say it says that in an   inertial frame no force implies no acceleration this is very very very important for us   in other words we do not infer the existence of force by looking at acceleration we compute what   the acceleration should be by looking at the force it is very very important

so what are we saying   we assume that we know how to distinguish free particles from others from the others

so we have to distinguish how do i distinguish because i know that if forces have physical origin   i should be able to find out whether a force is acting on a body or not   because if i remember the agent that is applying a force for example in the spring mass system it   is the spring in the case of electromagnetic electric interaction it is the charge   in the case of magnetism it is the bar magnet if i remove that for example in the case of magnet my iron rod stops experiencing a force

so i have removed the agency we assume that we   know how to distinguish free particles from the others now once we isolate these free particles   it has nothing to do with their state of motion that is very very important with respect to me   a free particle may be accelerating but still i should know

that there is no force acting on that   because force is caused by a physical
agency it is a physical origin once we do that then we identify   special
frames special frames of reference   and you have been given detailed lectures
on the concept of frame of reference in this very iit paul and they are called
inertial
so what are inertial frames of reference inertial frames of references are
those frames   in which a body which is not acted upon by any force will not
accelerate
so that is the statement   no applied force means no acceleration
so what does it mean
so let us make it even more clear in an inertial frame no acceleration is
equivalent to no force and this implies uniform velocity this implies uniform
velocity and what does uniform velocity mean magnitude direction both are
fixed to an excellent approximation the earth is an inertial frame but if you
look   at it very very carefully you realize that the earth is going around
its axis   and at some point not in your 12 standard or 11th standard but
later you will actually   find experimental evidence for the rotation of the
earth there is a very beautiful experiment   called the foco pendulum which
will tell you that the earth is actually rotating about its axis   in fact
there are other kinds of evidence like the coriolis force the direction of the
wind   which blows in the northern hemisphere and the southern hemisphere
which you will study when   you study centrifugal and coriolis forces there
are also other indirect evidence evidences like   the path of a river in the
northern hemisphere and the southern hemisphere
so there are some evidences but the direct evidence is because of the focal
pendulum   but that is a rather small effect compared to the revolution of the
earth around the sun for example
so it is an inertial frame if you go out of the sun and if you sit in a frame
in which the sun   is at rest that is a much much better example in fact
newton when he formulated his laws he   took a frame of reference in which the
stars the distant stars would be fixed that of course is not   a very good
approximation we know that very good assumption because all the stars are
receding away   but still by carefully eliminating known sources of forces we
should be able to get   at a good approximation for an inertial force and i
will assume   that we are in position so for such an inertial frame   and in
that inertial frame no force implies no acceleration that is very very
important point   therefore what galilean law of inertia tells us is to
interpret a kinematical result through dynamics   and here the dynamics is not
by the application of force but   by realizing whether a force is acting or
not
so what are we saying find a body on which   no force is acting then identify
the frame in which it will move with a uniform velocity   in that frame look
at a body which is accelerating and conclude   that there must be actually a
force acting on it that is galileo's great service to science
so there is the first discussion now we come to the second law second law this
requires a large number of concepts again combines kinematics with dynamics
but apart from kinematics the second law requires a very very important concept
called the mass newton defined it or understood to be quantity of matter
which should be distinguished from the concept of volume
so not volume this is not a very easy concept but if you assume that all
matter is built out of tiny particles   then it is very easy to see that it is
the quantity of matter
so you take an elementary unit say let us say that assign mass m equal to one
to that unit   then compared with that you assign masses to every one of them

and you simply count that is all what you have to do now it does not matter what the separation between them is that will only change the volume that will only change the density but it is not going to change the quantity of matter therefore

so long as you do not add matter or you do not remove matter mass is going to be the same

so you can imagine a balloon which is expanding for example because there is a certain pressure because of the gas molecules the volume is changing the density is changing but the quantity of matter inside the balloon is not changing

so that is something that we have to remember

so mass is the total matter content of course a big question is what else does the mass depend on for example does this quantity depend on whether that object is at rest or whether the object is moving newton declared that is independent of state of motion what does state of motion mean that is what i have written in that slide also it may be at rest it may be moving it may be accelerating in fact its acceleration may change with time because all kinds of forces are being applied or for that matter you may be looking at it from the wrong frame of reference not an inertial frame do what you will mass is not going to change both kinematically and dynamically kinematically is looking at it from a different frame of reference dynamically is by keep on changing the forces acting on it mass is a fundamental property

so that is the next newtonian postulate and we have excellent evidence for that nobody says that when a person is driving a car or flying in a plane the mass changed if an airline says that you are allowed to carry 25 kilos of luggage that 25 kg of luggage is understood to be the same whether you are here or flying up in the air at a speed of let us say 700 kilometers or 800 kilometers per hour there is experimental evidence for that of course therefore we are going to assume that although at some point when you do relativity special theory of relativity you are going to violate this and generalize that but never mind about at this point once we got the concept of mass the next thing that we require is the concept of momentum

so we say there is a great momentum the body is coming with a great momentum and generally it is understood when a body is coming with a great momentum it will have a great impact on us that means it is coming with a large velocity but it is also understood that even the mass matters

so at the same velocity whether it is a house fly that is striking you or whether it is a truck that is taking a hapless person there is a world of a difference

so we want to characterize the quantity of motion

so the quantity of motion depends both on the velocity and the mass

so newton in the simplest of the approximations rather with the simplest of the assumption it is not an approximation declared momentum to be mass into velocity declared this to be mass into velocity this definition is also not changed in relativity except that this mass will depend on the state of motion never mind about that

so now we have the concept of momentum so what is the statement that we want to make the statement that we want to make is that mass is not only the quantity of matter but also it reflects a certain resistance to motion

so if a certain force is required to change the motion of one unit of mass whatever its state of motion may be we would like to assume we would like to believe and then experimentally verify that probably two units of the same force would be required to modify the state of motion of two sets units of mass in exactly the same state of motion

so we want to have that kind of an additivity   and that is contained in the formulation of newton's second law

so please remember newton's   second law does not define a force what it says is that if there is an applied force

so if you come back to the slide and if you look at it i have written f applied that is   very very important for me because   if you say f applied is equal to dp by dt it makes no sense it is not an equality   we are saying that f applied is the cos and dp by dt is the effect it is very very important for us   to know that f applied applied means there is a physical agency somebody is pushing the car   somebody is pulling a rope somebody is dropping a stone and the earth is attracting it that is   the statement that we want to make

so this is of the physical origin this equal to dp by dt

so i have the momentum which is the quantity of motion that quantity of motion is changed   by the application of the force

so what are we saying this is the cause and this is the effect it's very very important for us of course if i am confident that i am sitting in an inertial frame   i can also use dp by dt to infer the applied force   but then i should make a number of experiments to verify that it is indeed because of the applied   force that is the way physics works and that is something that we have to remember

so so far   we have carefully enunciated and summarized the two laws of motion let me repeat them

so that it   gets fixed in our mind the first law identifies particles which are not acted upon by forces   and by virtue of that it isolates a special class of frames called the inertial frames of reference   the second law tells us please sit in the inertial frame   and in that inertial frame if you apply a force the second law says that then   the rate of change of momentum is equal to the applied force that is what the second law says

so these are the two steps that we have at this point it is good to give some examples of   forces because they are needed by us

so let us look at these slides the simplest example   and with which all of you are thoroughly familiar i am sure you solved any number of problems   is the spring mass system the spring mass system for small displacements around the equilibrium   position is governed by hookes law f is equal to minus kx where x is the displacement from the   equilibrium position then you have the frictional force i am sure again in your classroom   and in these iit pal lectures you solved a large number of problems involving friction you said that the frictional force is proportional to the coefficient of friction multiplied by the reaction   then you ask you know what is the minimum force required to move an object

so on and

so forth the third force again with which you are familiar or with which you will become   very soon familiar is the concept of viscosity you will do experiments involving stokes law

so you drop a small let us say a metal pellet a small metallic sphere   into castor oil in spite of the earth's gravitational field after a while that pellet will   move with the uniform velocity the terminal velocity because that is due to viscous force   all of you are familiar with the lorentz force

so what is lorentz force let me write that lorentz force lorentz force has two components the first one is the force due to the electric field   the second one is the force due to the   magnetic field combine them together this is called the lorentz force

so this is electric and this is magnetic

so you will you have already solved these problems the charge particle goes in

a circular orbit   in a magnetic field or you will solve it in the 12 standard
in a uniform electric field it will   suffer uniform acceleration
so on and
so forth and then of course we have the gravitational force
so i have listed essentially four forces so what are the four forces that we
have listed   the spring mass system which is macroscopic the frictional force
which is again macroscopic   viscosity which is macroscopic the lorentz force
which is electric and magnetic   and the gravitational force
so if you look at this slide you see that the last two the   lorentz force and
the gravitation i have italicized the letters are slanted because   they are
of a different nature compared to the first three forces the first three forces
are   not fundamental if i want to understand spring mass frictional viscosity
i have to introduce   more elementary forces whereas lorentz force is
fundamental there is nothing more fundamental   than lorentz force
gravitational force is fundamental and there is a consequence for example
whenever you have a frictional force or viscosity your total energy is not a
conserved quantity   all of you know that kinetic energy and potential energy
will be conserved let us say   you want to make such a statement they will not
be obeyed by viscous forces or frictional forces   that does not mean energy
itself is not conserved there are other forces there   are other objects which
we are not taking into account if you take all that into account then   there
will be a conservation of energy but gravitation and lorentz force are   in a
different league they are fundamental so when we do that the total energy or
the total   momentum or total angular momentum should be a conserved quantity
so these two are of a   different nature of a different category compared to
the first three or for example if i go back   when i look at the spring mass
system for small displacements
so let me write them   down here and that will make the concept very very
clear
so let me look at spring mass system
so if i write a force i will write minus kx but this is valid only for small
displacements
so if i stretch this spring a little bit more it can pick up atom like minus k
prime x cube   etcetera etcetera etcetera
so in other words depending on what kind of a displacement i give   the force
law keeps on changing
so that is why it is not a fundamental force   in a similar manner if i look
at viscosity or friction it can be constant for small velocities that is what
you assume when you   solve the problem of a block moving on the surf on a
rough surface it can be proportional to velocity   in fact at very very large
speeds it can be proportional to v squared for example if a   jet plane is
going therefore again you see that the form of a frictional force   or a
viscous force or of a spring mass system depends on what your displacement is
it depends on   what your velocity is it keeps on changing but when you look
at lorentz force or gravitational   force they are not going to depend on
anything they are valid at all distances they are valid   at all velocities at
all momenta that is the most important thing and that is the reason why we
say   that spring mass system frictional force viscosity etcetera etcetera
they are all derived effective   forces whereas lorent force and gravitation
are fundamental there are other fundamental forces now i move on to the
formulation of the third law   the third law is a very important law for us
because   in the second law we only look at the applied force and we made a
distinction
so let me write that down

so this is where you see the genius of newton in second law there is an asymmetry

so i write f applied is equal to dp by dt this is the agent cos and this is the effect

so i say the earth and this is a ball which is freely falling there is an asymmetry because earth is causing the ball to move and i am interested in the motion of the ball because of the earth's gravitational field i am not worried about whether this ball is acting on the earth or not

so newton's second law in some sense would be valid if your body a applied a force on a body b but body b did not reciprocate such things happen in nature in real life so there are lot of such interesting statements like a would like to be the friend of b but we would not like to be the friend of a there need not be a symmetry of that particular kind right these are relations a is related to b in a particular manner need not imply b is related to a in the same manner it could be a different thing but the third law of newton established as a symmetry and this establishes the symmetry in a very beautiful way

so what does it say i have a body a and i have a body b now when i say that a acts on b in a particular way and i am going to write it as f a cross b remember velocity momentum acceleration force angular momentum they are all vectors

so i will put it in this direction now let us say that i do not look at b but i look at a and i ask what might be the force acted upon by a b on a i can ask such a question and i will write f oh i am sorry here it should be ah this is correct a acting on b here f b acting on a and here it is f a acting on b so what am i saying the change of momentum of b is because of the action of a the change of momentum of a is because of the action of b on a newton's third law establishes a fundamental relation qualitatively newton's law tells us that if a acts on b b should act on a it cannot be a one way interaction it cannot be a one way deal it is not possible but over and above that it says that the force of a due to b is equal to negative of force b to a ok this vector sign must be on the force not on the particle i am sorry about that so they are negatives of each other this is very very important they are equal in magnitude but they are in opposite direction

so if you did that there is a simple exercise that i would like to leave you with and what is that exercise i do not want to work that out and that is if you go back to the slide for a minute if you go back to this slide for a minute i have written an equation

so please look at that slide and what does that slide tell you it tells you that dp1 by d p 2 equal to 0 ok there is a slight notation mismatch p 1 is the momentum of a p 2 is the momentum of b the third law tells you that the total momentum is a conserved quantity so please take this as an exercise work it out then if you are comfortable with that we have laid down the foundations for discussing the universal of gravitation which i will take up in the next lecture

so thank you have a good day you