so let us begin the last lecture in this series of discussions on gravitation

so what we are going to do today is to wind up the discussion on gravitational
potential energy   and then the escape velocity following which i am going to
discuss a little bit about satellites and finally   the implications of
newtonian gravity to cosmology because after all we call it as universal law
therefore it is a good question to ask what it tells us about the large scale
structure of the   universe there is yet another topic which is quite
important although we may not realize at   this particular point and that is
the concept of weightlessness
so this goes back   to the equivalence principle that we discussed at the very
beginning of this set of lectures
so we will also discuss that what we did was to start looking at escape
velocity essentially almost everything that we discussed will be using
gravitational potential energy concept
so what i did was to imagine that i have the surface of the earth this is my
radius r and there is a body here which has to be short let us say
perpendicular   to the surface at that very particular point so that it
escapes away to infinity escapes away to infinity which means to say that as
time becomes larger and larger it goes farther and farther away it will   not
be bounded by any distance if it gets bounded by some distance of course either
it will return   if it if it is shot perpendicularly upwards or if it has a
horizontal velocity it may either return   or it may get into an elliptic orbit
and that is what we mean by satellites when   it gets into an orbit but right
now we are interested in the escape velocity
so escape velocity is the minimum velocity which is required   to free this
body whatever let me call it as a from the gravitational field of the earth
so what we did was to look at the kinetic energy and potential energy at the
surface
so we wrote half m v s k square minus g m m by r e where r e is the radius of
the earth this is the total energy of the body and that should be conserved
as the body moves along the field of the earth's gravitational field   but now
i am asking for the minimum energy and therefore the minimum kinetic energy
and   therefore the minimum velocity which i call the escape velocity and that
would happen   if the particle were at rest far far away from the earth
therefore we put this equal to zero
so once you do this as observed my masses are going to cancel and we get a
neat expression escape velocity is simply given by root   2 g mass of the
earth
so let me write e clearly divided by r of e
so as we said the escape   velocity is independent of the mass of the body
which is trying to go away a rocket let us say we may not like to remember all
possible values for example you have the gravitational constant   you have the
mass of the earth you have the radius of the earth so   what we can do is to
rewrite it in terms of another constant min which you are all completely
familiar with and that is the acceleration due to gravity at the surface of the
earth
so i am basically revising whatever we did in the last lecture
so we are going to write m g equal to   g m e m by r e squared in writing this
we are of course assuming that the earth is a   perfect sphere and it is not
too bad in approximations again i cancel
so gm me by   re is nothing but gre therefore i can write my escape velocity
to be 2 g into radius of the earth and we all know g is of the order of 10
meters per second square that is what it is   g equal to 10 meters per second

square and radius of the earth is roughly 6400 kilometer
so if you substitute you will get a velocity around eleven point two eleven
point three   eleven point six etcetera etcetera
so whatever it is
so it let us say it is of the order of   eleven point five kilometers per
second and we got an idea of how large or how small this   velocity is by
comparing it with some of the known velocities of the very fast flowing jet
planes   and cars
so on and
so forth in fact it is large enough to require us to develop very special
technologies rocket technologies in order to escape for example when the
apollos were launched   by the united states by nasa they had to really work
hard because the rocket had to escape from   the gravitational field of the
earth and go as far as the moon is
so this is what we have   of course if we were to try to escape from the
surface of the moon   then moon is much much lighter than the earth therefore
the escape velocity will become smaller   probably about a few kilometers per
second i am not very sure of that and it is generally   argued that it is for
this reason that the moon does not have any atmosphere   of course we should
be very careful about making such a statement because   that assumes that ah
2.5 kilometers or whatever that magnitude is available to the gas molecules
that would depend on the temperature of the gas rms velocity of the gas
so presumably what you   should do is to go back look up your books look up
the internet and check what the temperature   of the moon is because on one
side it is very very cold and dark on the other side is always bright   it is
always one side of the moon that faces the sun the other sign is perillary
dark   because its period of rotation is roughly the same as the period of
revolution that is the reason so   probably the temperature is large enough
for the gas molecules to escape
so please work that out and convince yourself to check whether such a reasoning
is   correct or not
so nothing should be taken at its face value now this 11.5 kilometer per
second the number that i obtained assumes that the earth is stationary   it is
at rest but what is reality reality is that the earth rotates about it axis at
this point will ignore the fact that the axis is tilted at 23.5 degrees that of
course   is extraordinarily important because it is distilled that is
responsible for seasons   etcetera etcetera let us ignore that particular
fact   node earth is rotating about its axis therefore earth is not an
inertial frame earth is not an inertial frame because if there is an observer
who looks at us   since we are born to the earth we are moving towar together
with the earth with the same   angular velocity
so let me indicate that my earth is rotating
so these are my latitudes   these are my longitudes
so let me look at this point on the equator which is very very convenient   my
earth is rotating about this particular axis let us say then we know that v
equal to   omega r that is what we have in fact i should treat it as   r e
there is a certain velocity and my acceleration is given by omega squared r e
so there is a certain force that is acting on us because of which we are
rotating   together with the earth we are a part of the earth and there is a
continuous pin that is taking place   but from the viewpoint of the earth
surface itself we are not accelerating   and remember this acceleration is
inverse this is inverse acceleration because anything that has a circular
motion experiences a centripetal force which is inverse
so from the pure point viewpoint of an observer in the free space in the outer

space the earth is   rotating
so we are like a mass tied to a string from the center of the earth
so we are going   round and round and round there is a centripetal force
acting on us and that acceleration is given   by a equal to omega squared r e
again you can write an m and then m and you can cancel that   and that is one
feature which is common between the centripetal force   and also the
gravitational force it is given by omega square r e whatever it is   however
from the viewpoint of the earth we are not accelerating we are at rest   but
in every frame of reference if you want to balance all the forces that means we
have to   include a fictitious force which is balancing this physical force
this is a physical force   coming from the spin of the earth there must be a
fictitious force
so what we are saying is that   in the earth frame this is a very very
important concept in the earth frame we are at rest and therefore there is a
 fictitious what is fictitious means unreal it is not a real force it does not
have any physical   origin like gravitation or electrostatic force or a spring
mass system unreal force which cancels the physical force the physical
centripetal force which cancels the centripetal force that is what it is
so this physical force is acting on it and this is what is called as a
centrifugal force this centrifugal force is acting outwards and therefore what
we have is if i look at the   surface of the earth then what is happening
there is a gravitational force which is acting inwards   there is a
centrifugal force which is acting outwards which is given by m omega squared r
e   where omega is simply the angular frequency of the rotation of the earth
that is what we have   therefore i would like to leave it as an exercise for
you people to find out what is g effective
so let me write that for you
so what we have is you have the earth here
so the gravitational force is acting inwards the centrifugal force is acting
outwards
so my g effective is nothing but g minus the acceleration coming from the
centrifugal force which i will write it as omega squared r e that is what i
should write
so please remember omega equal to 2 pi by t and the period is simply given by
24 hours   which is 24 into 3600 seconds that is what we have   now if you
plug it in and find out the escape velocity
so please take it as an exercise if you plug it in and look at the escape
velocity this will decrease
so i am not going to work it out as i told you   but the answer is that it
will decrease decrease by about a kilometers per second i think eleven point
or eleven point three will become ten point four or   ten point five it's
about a kilometer per second that is what we have to remember now this
requires a little bit more analysis
so if i am sitting on the surface of the earth here the centrifugal force is
everywhere acting in this direction in fact   and the magnitude of the
centrifugal force keeps on decreasing and in fact here the force is zero
because omega is equal to constant but v equal to zero because the velocity is
equal to zero   force equal to zero that means as you move from equator and
you go towards the pole you are   escape velocity assuming that everything is
thrown upwards becomes smaller and smaller so   this is another exercise the
two people can work out   and what you find is that there is a not too
insignificant but not too large   variation from the equator to the north pole
so please work it out
so the problem is difference between the escape velocities at the equator and

the poles by the same token the escape velocity will also depend on how you throw the object for example   i can throw it in this direction or in this direction

so this is another thing that you   can look at

so again you can add your forces vectorially and you can find out what happens

so one is the equator and the pose and another is direction of let us call it ejection   direction of ejection

so please work out both these problems and then you will get a fair understanding of the concept of escape velocity the computation of this was extraordinarily important because as i told you this is what led to the development of   the great technology starting from 1950s or even earlier that was made   use of in order to develop the rockets that would escape from the surface of the earth   there was one indian who was quite an expert in rocket technology not to send it out of the earth   but as a military tool and that was the great tipu sultan

so that is something   that is celebrated by the rocket community that he had developed very very efficient rockets   because he had worked out the trajectory

so well that it would go and hit the enemy installations

so this is about the escape velocity what i want to now do is to look at the concept of potential energy and equilibrium   in a slightly greater detail and this has some very interesting and important lessons for us   which tells us that we should be very very careful in drawing conclusions without doing without looking at things carefully so let me start with two masses let us say   of capital m and let me look at a small mass m right at the midpoint we would like to contrast this with two equal charges q q now i have to be careful in the case of masses i do not have to   worry because gravitation is always attractive electrostatic is both repulsive and attractive   and what i will do i will put a small charge which is also of the same sign   here all the charges are of the same sign basically what we are saying is that   the larger charges the plus queues capital q's and capital m's are fixed they are not free to   move take them to be very very heavy here take the charges to be very very heavy but whatever is in   the middle is free to move and let us look at a rectilinear motion let us say that this charge   is straight to your bead this mass is straight to your bead and then these small masses are there   now what is happening in the second case is that both the charges at the end are repelling the   central charge

so what happens if i move a smaller charge to a certain extent in this direction   then what happens the repulsion here becomes smaller but the repulsion here becomes larger   therefore the particle tends to move to the right and if the charge moves to the left   then the repulsion here becomes larger therefore it starts moving to the right

so whatever your displacement is the restoring force is in the opposite direction in fact   it is a very simple example which all of you people work out many many times   it executes a simple harmonic motion

so if the perturbations are small it is going to   execute a simple harmonic motion that means we say that this point the middle point where the   total force is equal to zero where the force is equal to zero is a stable equilibrium position stable equilibrium position as far as one dimensional motion is concerned now of course i cannot dictate that this small q should move only along the   line connecting plus q the two charges for example it can move in this direction   or let us say in this direction a simple analysis will tell you that if it did that the particle   will escape away in other words this

stability is guaranteed only if it is constrained to move along the line connecting the two charges even the slightest displacement either above or below this particular line will make the charge move away all that you have to do is to make use of your law of addition of forces add them vectorially you will see that it is not going to work out so one says that electrostatics does not give you a stable equilibrium now what you can do you can try to find out of course this is not a general result the general result that any configuration of charges will not give rise to stable equilibrium is something that you will study probably in your 12 standard or if not when you go for a higher studies but the point in the case of gravitation is even more dramatic because even along a line there is no stable equilibrium because what happens at this point the total force is equal to zero the minute i move my mass slightly in this direction the attractive force from this becomes weaker the attractive force from this becomes stronger

so it will simply continue to move in this direction it will never come back so you give the most gentle push the most gentle nuts the particle will go away in this direction and again you can play around for example by putting two masses here two masses here

so on and so forth you will find that in any such configuration it is not possible to have a stable equilibrium position there are always points of total zero force but then a slight disturbance from the total zero force is going to disturb the equilibrium and that is a consequence of gravitational law that is something that we have to remember now when newton formulated his great laws the first law the second law and the third law he had the idea of absolute space with respect to which everything moves and the big question that was raised was what is the frame of reference that gives me absolute space because after all there are

so many frames of reference

so if there is water flowing and then there is a boat water is flowing with respect to the bank the boat is flowing with respect to water let us say this all at uniform velocities

so on and

so forth in fact this is not a example just given out of the blue because for example aryabhatta says that just as for a person in a boat in a stream all objects at the banks appear to move in a similar manner because the earth is rotating about its axis for a person on the earth the stars appear to go around the sun it is one of the most famous statements that you made

so there is always relative motion and even if you look at our own earth the earth is rotating about its axis or the earth is going around the sun and the solar system is traversing around the milky way

so on and

so forth therefore if i say that there is an inertial frame of reference in which newton's laws are valid then i need a physical approximation if not a physical example a completely accurate example of an inertial frame because if it were not there this formulation would be useless

so what did newton do newton looked up the sky and looked at the fixed stars we know that far far away the stars do not have any relative motion among themselves and they all appear to be at rest with each other and because it is because of this that we are able to have the ideas of constellation the shape remains fixed

so we say we say aries taurus capricorn sagittarius or in our own language you say whatever okay these patterns are fixed

so newton postulated that god has given the example of an absolute absolute space they deal with a capital d t okay inertial frame which is fixed in the

fixed frame of the stars because the stars are all fixed now the question is why is it that the stars are not moving even if they are all gravitationally attracting each other and the answer to that was that newton said that the stars are all uniformly distributed in space

so if you imagine an infinite space and there is a uniform distribution of stars

so you take any point on the sky then there is a uniform distribution of stars all around up above below whatever whatever therefore the net force on the star is equal to zero

so he argued that look here net force on the stars is zero

so every star is at rest that is what newton argued

so this is what is called as the static model of the universe and it is with respect to these fixed stars our okay maybe our galaxy moves our star moves our sun moves and we move

so this was in sense a sophisticated version of the aristotelian area where the earth is fixed and everything is moving around the earth but you see newton's laws themselves tell us that such a model is untenable because if there were a slight perturbation then this equilibrium would be destroyed let us say one star moved away a little bit then the neighboring stars would be perturbed and this perturbation would grow and it would be very very difficult to sustain this idea of a static homogeneous isotropic universe homogeneous means it is the same if you move along any given direction isotropic means it is the same in every particular direction

so that is the model that we gave and that is really a problem with newtonia although at the first instance it appears to be extraordinarily convincing there is a more sophisticated version of that due to stephen hawking but that you will study when you pass your 12 standard and go for higher studies and when you read something called the gauss's law which you will do in your 12th standard actually

so making use of gauss's law one can show that such a universe cannot be stable and indeed as hubble discovered the universe may be homogeneous and isotropic but all the stars are receding in fact the galaxies are all receding from each other in a following a law called the hubble law that is something that we have to remember

so stability is not guaranteed in the static case such a stability is not challenged when there is dynamics for example our planetary orbit the earth is probably a few billion years old a billion is 10 to the power of 9 years and it has been in a stable orbit and presumably it will continue to remain in a stable orbit for many more billions of years eventually the stability will be lost

so we have to make a distinction between the static description of gravitation and the gravitational effect when things are in motion that is something that we have to understand

so this is something which is useful for us to remember what i will now do is to wind up the discussion on gravitation by looking at the concept of satellites but there is one more piece of information that i would i should probably give you it suddenly occurred to me and that is about the second law second law of kepler is of course a statement of conservation of angular momentum but there is a certain qualitative understanding that you can have by looking at gravitational potential energy

so which second law kepler not newton's second law kepler's second law now let us say that you have the sun and the planet is in a circular orbit now what is happening along the orbit t is equal to constant what is t kinetic energy v equal to constant my gravitational potential energy why because r

is fixed because r is fixed   v is constant because t plus v is a constant my t is a constant and that is what you solved m   v squared by r and v is a constant that is what you write at any given distance   but i told you that the keplerian orbits are not necessarily circular but it can also be elliptical

so what i will do is to now look at a highly elliptical orbit which is exaggerated okay the sun is sitting somewhere here it is one of the foci that is something that you study in   your 12 standard in your conical geometry the point of the nearest approach is called perigee and the point of the farthest approach is called apogee all these concepts are well known   even in ancient astronomy with respect to the earth this is called perihelion now with respect to the sun it is called perihelion helios is sun and this is called aphelion some of you may have heard of einstein's dental theory of relativity there he speaks   of the shift of perihelion of mercury just in case you have heard now let us see what happens

so this is maximum distance i will call rm or dm and this is the minimum distance from the sun   d minimum d maximum that is what i call now along the orbit my total energy should be conserved

so what is happening at this particular point you look at the gravitational potential energy   at liquidal point to look at the gravitational energy again i will leave it as an exercise for you people to figure out where the body should   be moving faster and where the body should be moving slower i will leave it as an exercise   and in some sense you can relate it to the keplerian law which says equal areas are   swept during equal intervals of time

so this is one more thing that we can worry about now as the last topic let us look at satellite motion

so when we speak of satellites there are two kinds of satellites that we have to keep in mind   and this word satellite is peculiar to our solar system because in principle all planets   can be looked upon as satellites for the sun we are not worried about that particular part

so we are looking at the moons and the planets moons of the planets so planets have many many moons as i told you the earth has only one moon jupiter has probably   12 or such moons uranus also has many more mules

so these are called natural satellites all moons are natural satellites and they are of great interest to us because they tell us a lot about   the origin of the solar system if you study their behavior   how they were formed

so on and

so forth then we have what we call artificial satellites which we are able to launch and which we are able to put around the earth

so these are launched by us the humans

so what it requires is rocket engineering about   which i will make a few more statements in a short while now there is no reason to spend a lot of time trained to convince you that these satellites   play an important role they play great role in communication in remote sensing in weather   prediction in beaming all these programs for you the satellite communication

so on and

so forth   and of late over the last five or ten years when we are driving in a car and we are making use of   gps that is also due to the satellites so basically what you have done is to put a   whole area of satellites around the earth some of them are lola in some of them are   very very far away depending on what the needs are these satellites talk to each other and then   they are able to help us observe what is happening in the world all over the place monitor weather   change monitor climate change and help us in communication

so on and

so forth as i told you   therefore it is a good time to spend a little bit of our time to understand what is happening   of course there are more sophisticated satellites that one can launch for example if you imagine something like mangalyaan mars orbit mission you launched a rocket which went all the way up to the   mass and then it orbited mars

so it becomes a satellite of mars in order to understand   the behavior the nature the topography of mass temperature whatever whatever   the composition of the atmosphere

so on and

so forth

so that is also of great interest   and satellite technology of course requires very very advanced techniques and   cooperation of a whole lot of scientists engineers

so on and

so forth india is at the forefront of   the countries that have mastered this technology

so you people will be reading in the newspaper how   indian satellite launchers are able to launch not only our own satellites but satellites for google satellites for european countries satellites for american companies etc etc the most recent tweet   was when one of our rocket launchers actually launched more than 100 mini satellites very   very small satellites nano satellites all of it happened within a matter of five or six minutes   actually you know like your gun shoots bullets

so this rocket was able to shoot the satellites   and the important thing was that it was able to put them in the required orbits   that is the challenge in technology

so we have a big organization and in fact we have a whole   education institution dedicated to that indian institute of space science technology

so those   of you who really want to become astronomers astrophysicists aviation technologists should   really study more and what i am going to tell you in the next few minutes is a glimpse of what i am   what is happening one very important concept that we need is that of geostationary satellite

so when we say geostationary satellite what we are saying is that

so let us say we have this earth i will make it into a big blob and we launch a satellite   and the satellite goes around in an orbit at a distance d let us say from the center of the earth

so given this distance i know the period kepler's law newton's law of gravitation   essentially gives me but then the earth itself is rotating about its axis

so what i want to do is   to synchronize the period of the satellite with the period of the earth that means if i look up   suppose i launched it above me and i saw it above me i will continue to see it above me   the other person somewhere continues to see it at the same point because   it is essentially co-moving with the earth as far as the angular motion is concerned

so these   are called geostationary satellites

so how do we accomplish that the answer is very simple

so i should go back i am going to write m v squared by r is equal to g m e m by r   okay i i use the distance d

so r equal to d this is the distance from the center of   the earth that is what i have i should put an r squared here

so i cancel this

so i cancel this   and now i will write v equal to omega r in fact that is what we were doing earlier also   therefore what am i going to get i am going to get omega square r squared is equal to g m e by r   that is what we have

so if you remember that omega is equal to 2 pi by t that is the period
so what is going to happen now
so this will tell me that 4 pi squared by t square is equal to g m e by r cube of course all of you would be highly familiar with this expression i may have a problem because you see t squared by r cubed is a constant 4 pi square gme is what you have
so if i were to write the expression for t what will this be my t squared is essentially 4 pi squared r cubed over g divided by the mass of the earth
so i do the square root i do the square root and i get the period
so what do i do now what i do is to demand that this t is equal to 24 hours which is 24 into 3600 seconds that is what i will do the only parameter that i can change is r the distance from the surface of the earth
so well you know gravitational constant you know m a i cannot convert it into acceleration due to gravity because this r is the distance from the surface of the earth therefore if you want i can write r equal to r e plus d that is a better notation and this d is what i have to adjust
so i won't find spend any time working this out
so if you did that you will get d to be a very very large number of the order of twenty eight thousand five hundred kilometers which is practically giving the escape velocity just that it will also have a horizontal component of the velocity because of which it will be in a circular orbit we have to understand that that is what we are doing this is a very large number and that means you need a really very very powerful rocket to launch this
so these are the geostationary orbits now what is the advantage of the geostationary orbits the advantage has been very well described in your book which i was looking up today you know our earth has an atmosphere and the uppermost part of the atmosphere is your ionosphere basically ionized gas
so when you try to do radio communication ionosphere reflects radio waves so suppose i beam send a beam here it gets reflected at this particular point and it can reach depending on the direction at which event it can actually get reflected and it can reach various parts of the earth that is how we are going to propagate that through repeated reflections but televisions require microwave range radiation in the microwave range and my ionosphere does not reflect
so the big question is how is it that a satellite channel is able to beam its programs all over the earth
so what you now do is to put a geostationary orbit and my satellite antenna my emitting antenna is sitting here whatever that thing is broadcasting antenna it sends microwaves which goes there now my satellite takes it synthesizes it and beams it that is what it does
so you can imagine if you had for example two such transmission stations and there are two such satellites that may not necessarily be the way it works
so this will take care of this part of the hemisphere this will take care of this part of the hemisphere it can be again my ionosphere is not going to interfere with the propagation of the microwave and you are able to see your football matches or whatever program that you want
so this is the under advantage of geostationary satellite but as i said this requires putting satellite at a very very large distance now there is another category of satellites called polar satellites the geostationary satellites are in the equatorial plane and they go round and round my polar satellites
so if i did that their motion is from north south north south north
so at some point there will be about the north pole and they come down they will be above the south pole

so on and
so forth that is this motion and these are all low level satellites
so what is happening in the case of these low level satellites for the
geostationary equatorial   satellite it was sitting at the same latitude
whereas here you are cutting across the latitude   because you are moving north
south or south north therefore you are able to monitor the weather   depending
on whatever your velocity at different times of the day at different parts of
the earth   it is useful for remote sensing it is useful for a whole lot of
things for example i want to know the   rate at which the continents are
drifting i want to send signals and i want to get them back i want   to know
how the crowds are moving i want to know how the cyclones are developing these
are all very   very important for this this low level satellites may be 500
000 kilometers is what they are they   are launched barely about the atmosphere
and these are also very important and india has launched   a whole lot of them
so much
so that recently when there was this highly threatening cyclone   that was
threatening to hit the orissa seashore there were a lot of foreign satellite
weather   monitoring centers which were saying that all the people should be
evacuated because it is going to   wreak havoc but the indian meteorology
department was confident that such a thing would not happen   they did not
evacuate people and they were proved right because they were in possession of
very very   accurate data which came from the observation
so these satellites are also very important
so i think we have fairly conclude covered all the topics that we wanted to
cover
so what i want to do is to conclude this lecture by one very simple concept
namely weightlessness and probably if i have time i will also tell you
something about the scientific   creativity that one shows when one is
launching satellites or rockets but first let us discuss   weightlessness i
had almost forgotten that now let us say that we have a spring mass system
okay
so this is another block is that okay and this is in a table on a table
whatever okay now if i were to move the table   on the surface of the earth the
whole table moves nothing happens to the spring mass system   because it is
simply moving equipotential surface and this is moving at a uniform   velocity
nothing happens to the spring mass system
so this distance remains the same and   if it is in the equilibrium position it
is in the equilibrium position however if i have an elevator   and then i put
a spring and i put a mass what is going to happen now   this mass is going to
come down that is the concept of weight because of the gravitation   because
here when this mass is free to move the top mass is not free to move therefore
there is   a tension that develops the gravitational pulls it a little bit
down the potential energy is   stored here and then the bob executes a motion
oscillatory motion that is what is going to happen   and the most important
thing is that this is not free to move now suppose i remove the support and
i drop the whole thing the top portion and the bottom portion
so the whole thing drops free   fall that is what it is called they move with
the same acceleration now there is no tension that is   building up the
equilibrium position remains the same there is no elongation in the spring
or there is no compression in the spring and that means my weight this body has
become weightless this body has become weightless and this is something that
all of us experience   for example when we suddenly trip and we are about to
fall there is a momentary   weightlessness
so what is essentially happening is that in the rest frame of the body there

is a centrifugal force which acts upwards which cancels the downward
gravitational   force exactly and there is practically no force that is acting
on it
so this is what is called as   weightlessness the mass remains the same but
weight changes
so let us remember this is mass mg is the weight and we are saying that the
body does not experience any   acceleration because it is freely falling what
i mean what do you mean by acceleration   this body does not experience any
acceleration with respect to the spring   whatever the top bodies that is the
weightlessness that we are speaking of and this is the same   psychological
feeling that we experience when for example as i told you there is a
momentary   free fall
so people who dive from a swimming pool on from the diving boards of a swimming
pool   tall diving boats of swimming pool experience this feeling of
weightlessness very very well   and this weightlessness is of course there
even when you are in a free space because   you are not going to experience any
force therefore what we are essentially trying   to say you may not be able to
understand at this particular time is that a freely falling body is   as good
or as bad as a body in the body in a free space without gravitational field i
will not say   anything more than that this is the basis actually of
einstein's principle of equivalence and   general relativity but we'll leave it
at   that to conclude i want to give an example   of ingenuity in rocket
launching and that was in our mars orbit mission mangalyaan this is a very
famous story you might have heard of it in newspapers or in   on tv shows
etcetera etcetera who is it that we are able to send a rocket to   mars now
once the body goes in free space there are no external forces   acting on it
therefore what you have to do it continues to move with uniform velocity   but
then if you want to reach your target as early as possible then you are in for
trouble because in   free space there is no other force
so what do you do you take a rocket and then you burn the fuel
so that this backward thrust actually gives you the enough acceleration that is
what you do   and this is exactly what nasa did when they sent of course their
rocket was much heavier when they   sent their rocket on mars mission what
indian satellite scientists did was something slightly   different they said
that there is another way of actually accelerating
so what they did was this   was my surface of the earth you launch a rocket
and my sun is sitting here
so it goes sufficiently   close such that the gravitational force of the sun
is not negligible and this rocket was put   in a highly elliptical orbit of the
sun now the minute you are in a highly elliptical orbit   of the sun
gravitation comes and says there is acceleration there is acceleration and not
only   that the acceleration is natural you do not have to put anything
because it goes round and round
so what you do is to wait until you get as close to mars as possible
so this mathematics you have   to work out as soon as you reached as close to
mars as possible because of this acceleration   you did not have to spend any
fuel on that because the sun's gravitation was doing the job then you   fire
some secondary rockets and put it on an orbit around the moon
so this was an extraordinary feat   which was out of the box thinking as people
say which was held apparently it also saved a lot of   money
so there are big noise that are involved so the total money spent on mangalyaan
was about 450   crore rupees whereas today even big hollywood or bollywood
movies make have a budget of the   same order if you look at any of the movies
one example that was given was that of gravity   i think this was deliberately

chosen because we are looking at the gravitational field   the budget of this movie called gravity was much more than the budget of mangalia and in our own country recent bollywood movies have had budgets of 25 250 crores 300 crores of that variety

so we   see that it is one thing to know the principles it is another thing to put it to good use and   that requires solving lots and lots of problems and constantly thinking on it i hope you would   do that let us conclude this set of lectures on gravitation at this particular time best of luck you