Rocket Propulsion

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Lecture No. # 01

Introduction

Well, good morning. You know this will be our first class on rocket propulsion and in this class today what we will look at is, what is the subject on rocket propulsion, how it differs with different propulsion subjects, what are the aspects we must consider. We will go through the course contains what we have and then see the type of books we what we must be referring to and then get started with the course. May be the introductory part will take some something like ten fifteen minutes and then we will get started with the course. Having said that.

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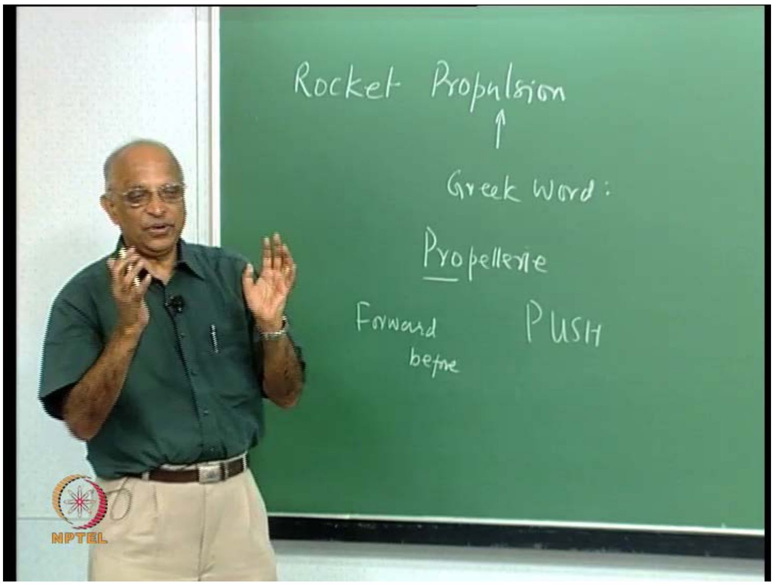

Let let us first take a look on, what this subject on Rocket propulsion is above. You know the word propulsion, if you see comes from the Greek word is known as propellerie pro pellerie. You know the word pellerie in Greek means push, therefore we are talking of something pushing. Pro as you know mean something like forward or before, therefore the word propulsion means push forward and therefore, whenever we talk of any subject on propulsion, what we mean is pushing forward.

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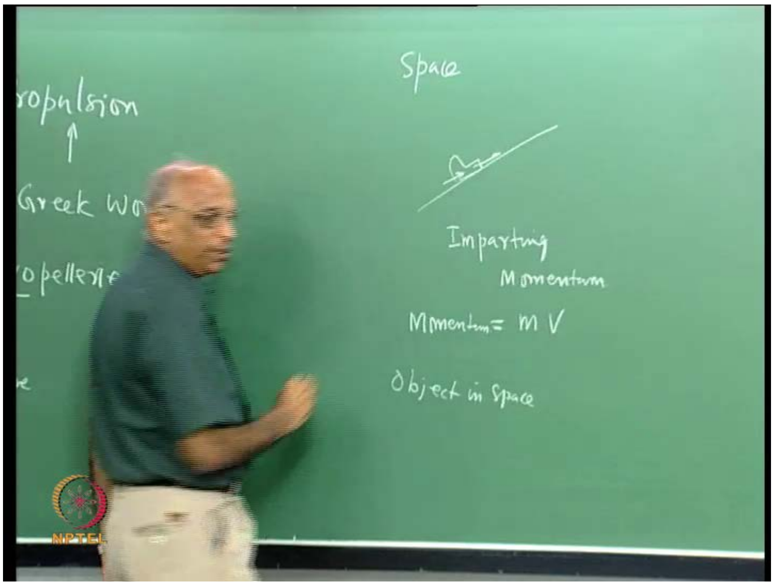

let us take the simple example of let say, I have something like a car which has to claim up a hill ,up an inclined plane, what we do, the engine of the car pushes it forward and by pushing I mean, you are changing the velocity of the car or you are imparting a momentum to the car. What is momentum, momentum is change of what you are imparting some change of momentum to the car.

How would you define momentum how would you define momentum. what is momentum, how will you define in any any anything, we say the car has a velocity v, it has the mass, if you say mass into velocity is what is momentum and if you want to change the momentum, you have change the velocity of the car.

You give some velocity and you have what we call as momentum is it right. Now you know in space deep space, we do not have something like atmosphere and therefore, the act of imparting momentum to the to the object in space is what we deal with rocket propulsion. I will again repeat this all, what we are saying is propulsion means pushing objects and when we say rocket propulsion, we are dealing with pushing objects in space.

Space means anything beyond us, may be up there therefore, may be first we must get an idea on what space about. Let us say, what we mean by space we have to understand but before getting that, let us just quickly get through some idea on what this whole course is about and how we are going to organize our next, let us say forty classes hours. To be able to organize ourselves.

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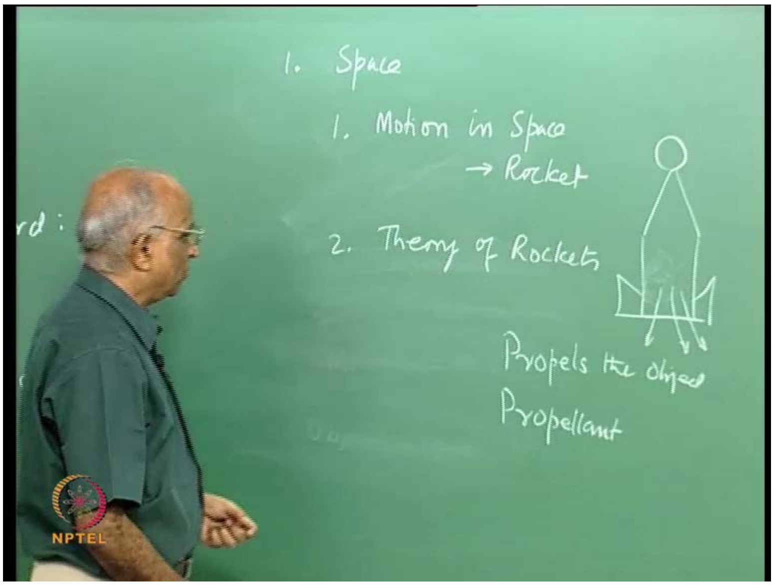

Let let us let us let me get started here. May be the first class starting today, we will look at what we meet by the word space, what constitute space in what way is motion in space is going to be different than motion on the ground. That means, we talk about motion in space and once we know how motion takes place in space may be, we will able to find out what is the exact requirements that rocket must do.

You know see to be able to see I design a rocket, a rocket could be something very small or it could be huge. I must know what is the requirement of motion in space. So, as to go and we a particular rocket therefore, the first chapter will deal deal with motion in space and how we go about converting this motion in space to the requirement of a rocket. Once the requirement of a rocket is clear to us, the second chapter will deal with let us say, the theory of rockets.

You know, I would like to ask a question, why should a theory of rockets be different from a theory of a car or let us say, I have a gun, I fire a gun the bullet leaves the gun in what way is rocket different from a gun. What is your your thinking on it? Any any anybody to could answer that, Paden, you say it is a non air breathing system. So what, we will get into some details of air breathing, non air breathing. Your point is ,it,s a non air breathing system but in what way should a rocket be different? Let us say, I have a gun, I fire a bullet from a gun I am also leaving at high velocity.

Why should we call theory of rockets, why what what is the great theory about it. See it so happens, what happens is in in a particular rocket let us say, we just assume a rocket is like this. There is some mass which is available in the rocket, what is mass which is available in a rocket, the mass must be able to push forward. That means, it propels the object and what is the object, you have something like a space capsule which it pushes forward and this what propels is what we call as a propellant.

By propellant in a rocket, you mean the substance used for pushing up the rocket or propelling the rocket. Now in the case of a rocket, the propellant is continuingly getting exhausted, it leaves the rocket and therefore, the weight of the rocket keeps coming down, and therefore compared to a car in which I carry something like ten litres of petrol or something like this, I carry tons and tons of propellant which is ejected out and therefore, the theory of a rocket is different from a car or a bullet.

And therefore, we have to look at the theory of a theory of a rockets which the second chapter. Having finish the second chapter, we will have to say we told ourselves to push a object, we need to give change of momentum and therefore,

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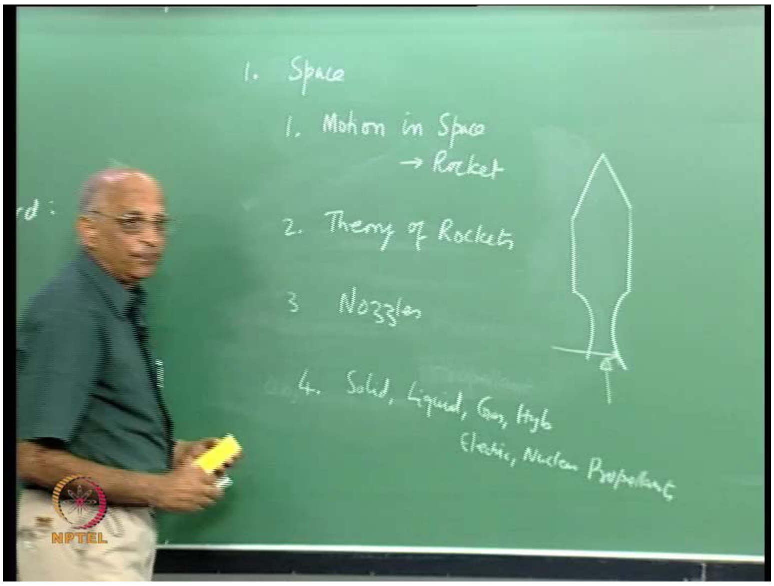

We will go into nozzles which produce high velocity and help us to achieve a large change or impart a large change of momentum to the object in space. You all have studied nozzles in your gas dynamics course right. Anyone has not done it or we will start from the basics, go through the basics of nozzles, advance nozzles but it is quiet an involve chapter.

Because if you have something like a rocket like the and let me sketch a rocket for you. May be the internal configuration I have something like a nozzle here. The flow must run full otherwise if some portion does not run full, I could get something like a side force in addition getting a force in this direction. Therefore, the theory of nozzles is quite involved and the third chapter we do here is on nozzles.

The forth chapter, we will get back into the propellants or what is used for propelling, could either be a solid propellant, could be a liquid propellant, could be a gaseous propellant, could be a hybrid a combination of these things, could be electricity itself, could be nuclear, could be anything right. And therefore, in the fourth chapter we will study about the different propellants.

What are the characteristics required to make a good rocket and that is what we will study about propellant solid, liquid, gas, hybrid, electric may be nuclear propellants. Once we are clear about the propellants, we can go into the details of the rockets and then we will ask ourselves. Well

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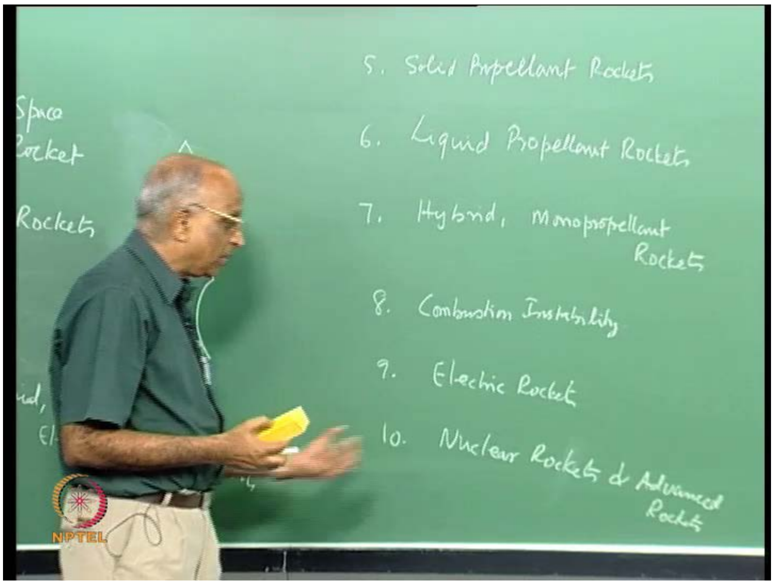

the fifth chapter would be solid propellant rockets. And this type of rockets has been used very extensively by in India both for GSLV, PSLU maybe we will have to look at it, look at the design considerations, what constitutes a solid propellant rocket.

The sixth chapter, would be something on liquid propellant rockets. They are more versatile and in this chapter, we will basically look at the following, may be we will take a look at what are the cycles of operation, in what way it differs from a gas turbine combustor, may be an IC engine and what are the modelling features, you know the liquid propellant rocket is something which is evolving and when we talk of cryogenic propellants, its again a form of liquid propellant and differ, we will spent quite some time on this.

The seventh chapter, would be something like maybe since we have studied solid and liquid, we can study something on hybrid and something like a single propellant, what we call as mono propellant rockets. This would finish the different type of rockets, how to make them, what are their features and what are the problem areas in rockets. And once we are clear about it, we go to an advanced subject which I will call as combustion instability.

See this this particular chapter on unstable combustion on instability is particularly important for PG and research students. Since, we are going to look at what causes instead of having a steady thrust is it or will it oscillate under some conditions, instead of burning steadily, will it explode under some conditions and that is what we study on combustion instability. We will deal with it in something like six to seven classes it tends to be important and this is some area where in research works still goes on in the area of rockets.

The ninth chapter, will be an evolution of some of these things may be we will look at electrical rockets. What do you mean by electrical rockets? We told ourselves for any rocket, we need to push an object in space. We will try to see how we can generate electrical forces. Different forms of generating electrical forces or forces using electricity or (()) electromagnetism and then we will deal with this particular chapter on electrical rockets.

The tenth chapter would be nuclear rockets and other advanced rockets. What do we mean by nuclear, I could use nuclear energy to generate a force, I could also use maybe I could use space time curvature like relativity to generate a force. And some of these things will consider as the last segment of this course. Having said that, let let me also briefly briefly on one or two books which I will be following in, which are good books for this particular course.

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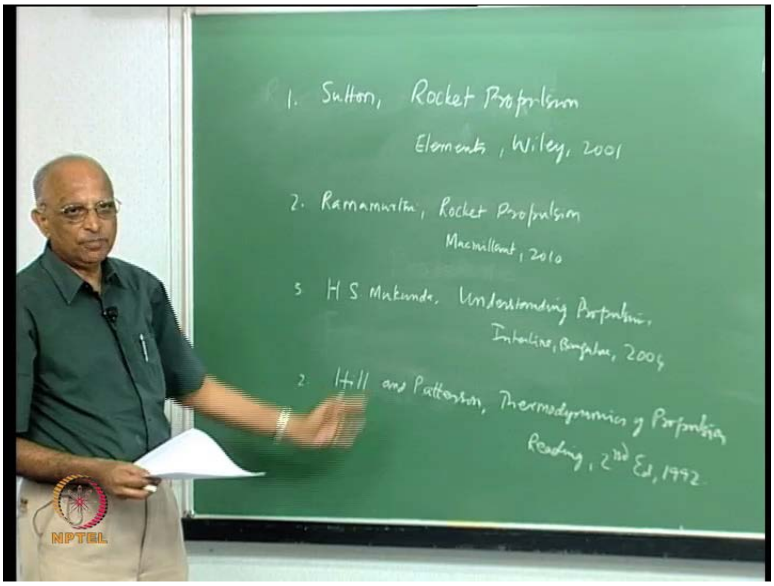

The first book in on by Sutton, it's on rocket propulsion elements. I think the publisher is Wiley, year of publication is 2001. You know this book gives a very good description of rockets but the mathematics of rockets is missing and I in had published one book, the name is rocket propulsion. It was published by Macmillan, in 2010. This was based on my teaching of the course over the last 6 to 7 years.

The third book which gives the good description about the different rockets is by H S Mukunda, the name of the book is understanding propulsion is published by interline, Bangalore and I think it is in 2004, it was published. I think one important book which I should have afforded the beginning is a book by Hill and Patterson, the name of the book is thermodynamics of propulsion, the publisher is Reading. It is an old book it was first published, I think in nineteen seventy or so but the second edition is published in 1992. We have copies of these books in our library right.

Therefore, this is the beautiful book deals with the thermodynamics of propulsion. This deals with the description of many of the propulsion elements, this combines aerospace and rocket propulsion together whereas, this is little book bit more mathematical in the area of propulsion. We we should keep this and as I go along may be, I will introduce more books on specific subjects well this is the background of the whole course.

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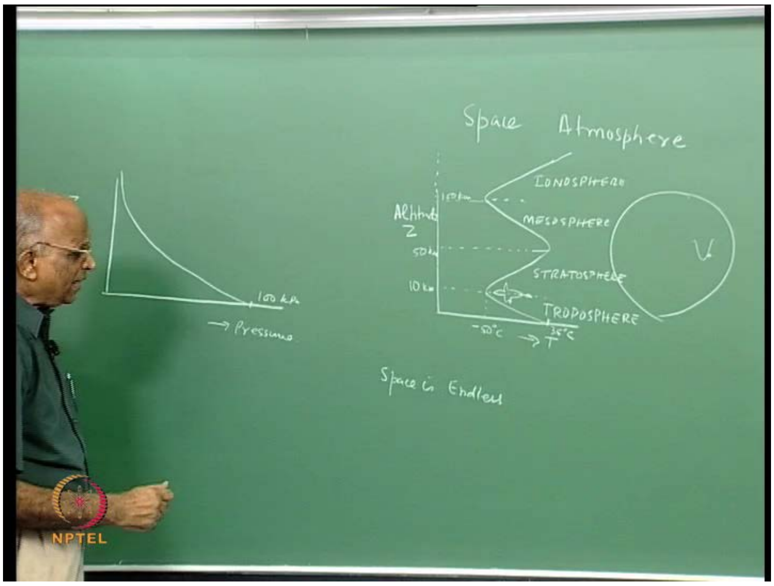

And I think lets gets started now. Let lets lets get started, what do we mean by motion in space, anybody would like to has had a guess in what way it will be different than on a ground.

Let us first define what is space, how do we define space, anything above is space can we say or how how how would we define space, we go on up and up or we go sideways go to infinity that is space or how how how can we define space, how do you define space? We talk of space capsules, we talk of some planets, we talk of galaxies, how would you define space. See you you are telling me that anything outside the atmosphere is space.

Therefore, let let lets lets take a look at your question and examine, what really space is about and what do you mean by atmosphere. Let us say, we are here, let us say Chennai over here. Chennai is normally a hot and let us try to plot the temperature in the air or in the atmosphere above Chennai has a function or let us say altitude z. We know, we say since the sun is heating the earth, earth tends to get hot.

May be the temperature at the surface of the earth, let us say is around 35 to 40 degree centigrade. As we go higher and higher up, that means as we increase the altitude the temperature decreases until at an altitude of around, let us say around 10 to 11 kilometres, the temperature is around minus 50 degree centigrade. These are notional numbers and thereafter the temperature begins to increase again. That means, temperature drops to minus 50 degree centigrade at an altitude of around 10 kilometres and then begins to increase again.

Why does the temperature decrease, the earth receives the radiation from the sun gets heated and the earth surface of the earth is relatively hotted and has you proceed away from the surface, the temperature drops and this zone where in the temperature drops is known as troposphere. The reason why temperature drops is earth is relatively hot as we go higher up the temperature drops.

A jet aircraft flies at an altitude of around between 8 to 10 kilometres. Let us say, this is where the jet aircraft flies and it flies where the ambient temperature is between minus 40 to minus 50, you would have heard this announcement saying the, your your aircraft is cruising at an altitude of around 10 kilometres where in the ambient temperature is of the order of minus 45 degree centigrade or minus 50 degree centigrade.

If you go up still further the temperature drop, the temperature increases, the increase in temperature is because in this area you have lot of ozone available. The ozone sort of sort of gets heated by the solar radiation, it absorbs the solar radiation, the temperature increases and this increase manifest for another 40 to 50 kilometres.

Let us say 50 kilometres and the the region of the increase temperature is what we call as the stratosphere but when we go still higher altitude let us say higher than 50 kilometres, the pressure in air is so small or in the molecules of air are so small that they they are unable to absorb any radiation or because there is nothing air absolutely.

Therefore, the temperature again drop to an altitude of let us say around 100 kilometres or so but if you go to still higher altitudes you have the molecular oxygen which absorbs the molecules individually absorb the radiation and they increase in temperature and you have the temperature going up.

The region where in the temperature drops again is what we call as a mesosphere and the region of temperature increase because the individual atoms of let us say oxygen or let say molecules of oxygen they absorb the radiation, that is individual atoms getting heated or individual molecules getting heated is what we call as the ionosphere. This continues for something like 100 to 200 kilometres.

If I were to plot the pressure of air the pressure of air may be has a function of an altitude again I plot the pressure, this is altitude z in let us say kilometres. At the surface of the earth, the pressure is around 100 kilopascal and the pressure monotonically drops, keeps on falling until maybe at the ionosphere, you hardly have any risible quantities of air left, its all free molecular flow and this is where we, said that the temperature increase is.

The concept of temperature fails because there is no continuum in this region. And it is the individual molecules of some of these gases which tend to get heated to high temperature and the temperature increases again. Now the question is, what do we define as space, anything above the surface of the earth going through the troposphere, stratosphere, mesosphere, ionosphere and beyond.

That means, we says space is sort of endless. It keeps on going to infinity and therefore, we must be capable of defining what constitutes space,

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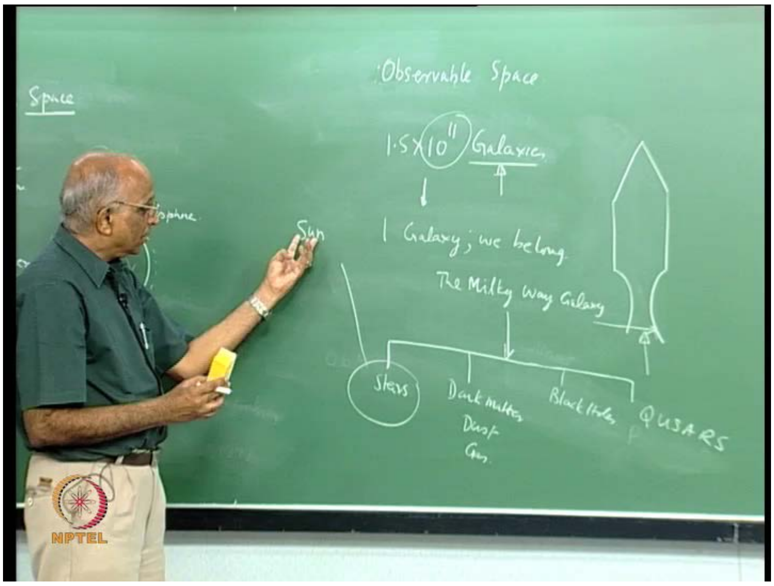

which I do subsequently. There’s no no extend itself but how do you define something which is endless. Therefore, it’s necessary to to have a look on what constitutes, what is there in space.

And if you go back and see what is there in space, you see that there are something like 1.5 into 10 to the power of 11 galaxies not in total space but in the space which we can see, which we can observe rather I must correct myself and tell you that in the in the observable part of space and how do we observe, may be through a telescope I observe, I observe something in the observable space.

We have something like 1.5 into 10 to the power 11 galaxies. That means, space is still beyond but what I can see is only this and how what are galaxies, see all of us suddenly we are introducing new words. By galaxies, we mean you have a typical stars gravitationally bounded system of stars and each galaxy has a system of stars and lot of may be some dark matters, something like gas, dust and all that it at.

It could contain lot of things and out of these 10 to the power 5,1.5 into 10 to the power 11 galaxies, if I consider one galaxy to which we belong, that we say is the milky way galaxy right. Therefore, what we have said is, space is endless, in the near observable space, we have something like 10 to the power 11 galaxies and our attention has now come to the galaxy which we belong to or in which we live, which is called the milky way galaxy.

Why the milky way, it comes from the some roman or Greek mythology, which says that the colour is something like milk and stuff like that or there are some stories around it. We will not get into those details but just say may be when we talk of number like 10 to the power of 11, we are something like 1 over 10 to the power 11 part of observable space and when I talk of a number like 10 to the power 11.

Even though, I write it like this, it is as if saying that on the beach you have lot of sand particles and I go and I put all the beaches together and I take one sand particles this is the amount of space I am considering from the near observable space. Therefore, we are shrunk ourselves and you can see, you know how small we are in relation to space really and this milky way galaxy.

If you really see what constitutes the milky way galaxy, well in the milky way galaxy you have a large number of stars. And what are stars, massive objects in which nuclear reactions are taking place. They emit light they emit heat. Then you could also have something like dark matter, you could have in between the stars, you could have some gas and stellar dust or dust as it well, let us say dust could have gas, you could also have lot of different things.

You know you all could have heard of black holes, what are they, you could have it in in we have it in our milky way galaxy. What are what are black hole, you know what happens is sometimes this stars shrink to very small size. Therefore, you have infinite mass concentrated in a very small volume and when we have large mass concentrated in a small volume, it is capable of attracting, that is the gravitational pull will be large.

We will get into the gravitational pull towards the end of this class and therefore, what we say is we will have black holes, we could have other objects like quasars. What do you mean by quasar, quasi thing related to stars, quasi star related radio sources and these quasars are objects which are again travelling at near about the speed of light itself.

Therefore, you have lot of things there in our milky way galaxy and out of all these out of all these stars, I figure out one star which I call as the sun. And therefore, we focus ourselves maybe from 10 to the power 11 galaxies, we have come to one galaxy out of all this, we have come to the sun which is a single star and it is about this which we will be basically interested in it.

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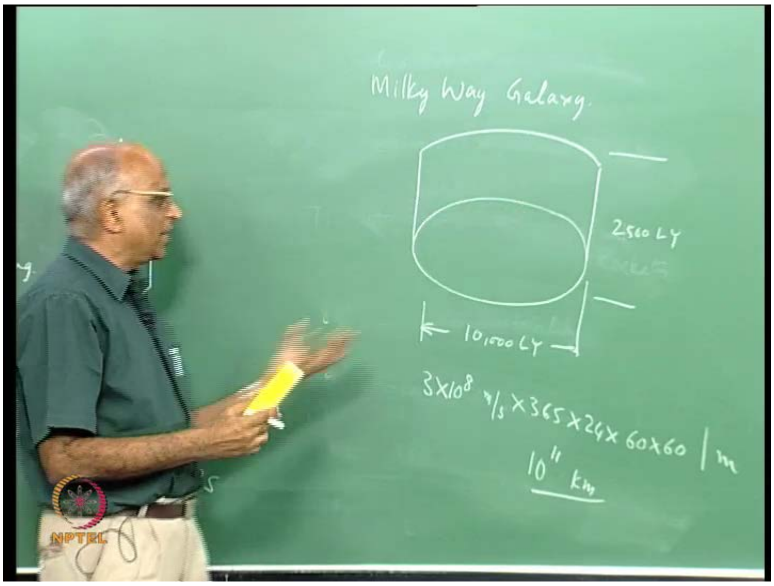

Let let let us put it together, let me put some dimensions out. If you look at the milky way galaxy, let us see the extent of this, it somewhat cylindrical in shape. The size or the diameter is around 10000 light years. Why do I say light year and not say kilometres because it so huge you know. And what is the what is the light year? The distance travel by light in one year.

The speed of light as you know is10 to the power, 3 into 10 to the power of 8 meters per second in 1 year have 365 days multiplied by 24 hour multiplied by 60 per minute, 60 per second. And therefore, one light year will therefore, corresponding correspond to so many meters which should be around, I think something like 10 to the power 11 kilometres or so, approximately it will come to around 9.5 into 10 to the power 10 kilometres or so.

Therefore, we are talking of a diametral content and it something like cylindrical in shape and the duct of this is something like one-fourth of this something like 2500 light years. And in this you have number of stars as we say number of objects and we are considering one particular star call the sun.

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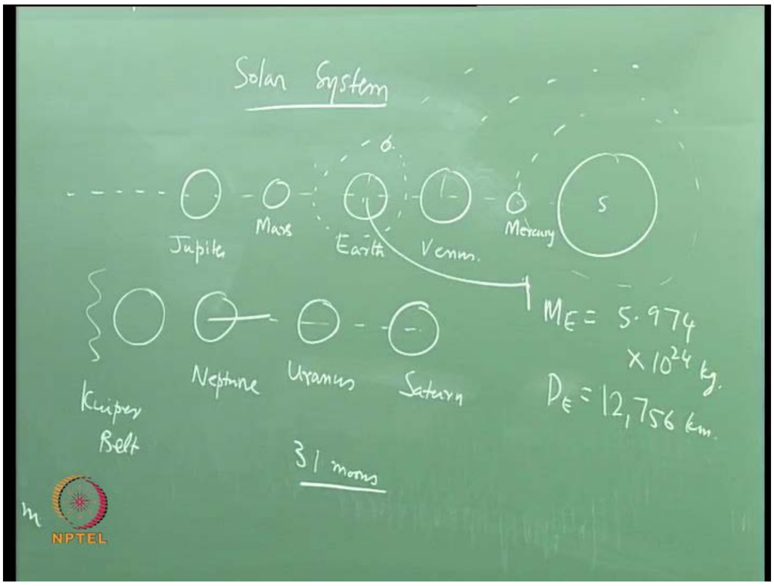

Which we say is the solar system with which we are concern. Therefore, this is all in space right, we talk we started with number of galaxies in the endless space and now we come to the solar system.

What is the solar system consists of, it consists of the sun, a single star mind you out of the large number of stars and you have large of a planets. May be starting from Mercury, then you have Venus little bigger. Then we have the earth, what is next ,mars what would be the next one, Venus. Then what what further let us say, I continue this over here mars, then Jupiter fine yes. Mars, Jupiter, I am sorry then is Venus no.

Then what what will be the next one Saturn, two more Neptune, Uranus and Neptune. Therefore, you have 3 plus 5, 8 planets which are going around. You know previous we we had another planet known as Pluto but that has been decommission because it is not fully formed. It is something like a loose mass which is still going along with a belt here which known as a Kuiper belt.

I will back to this belt because it gives lot of inputs. What we need to do, what we need to understand about, may be some asteroids coming and hitting earth and all. That we will get back to this shortly but all what we are saying is. In this solar system, we have something like eight planets going around the sun and this the near part of space with which we are we are interested in it.

This solar system also consists of something like 31 moons and how do we define a moon, we tell ourselves yes, there are certain objects which go around the planets and they go around like satellites around it. There are 31 moons and earth has a particular moon which is going around the earth and this is the moon of the earth. So also, we will have moon for Saturn, we have moon for Jupiter and there are something like 30 other moons which are available.

When we are dealing with all this is necessary to have some idea of what constitutes these these planets may be earth if you take, let us put down the mass of the earth, let us put down the diameter of the earth. I have it with me here let let let let me. 5.974 into 10 to the power 24 kg, the diameter of the earth is 12756 kilometres. I think these numbers are important, I I will circulated table to you giving the mass of the different planets and their diameters. But just to get an idea may be mercury is about the smallest planet around one-third the mass and diameter of the earth as it were.

While I think the largest would be something like Jupiter might be the planet that we have. Having said that, you know what happens all these planets go around the sun and it is these motion of planets which give or which prompted Newton to formulate the universal law for gravitation. I think I should repeat this point in a in a slightly different way let us take a look at what I want to say.

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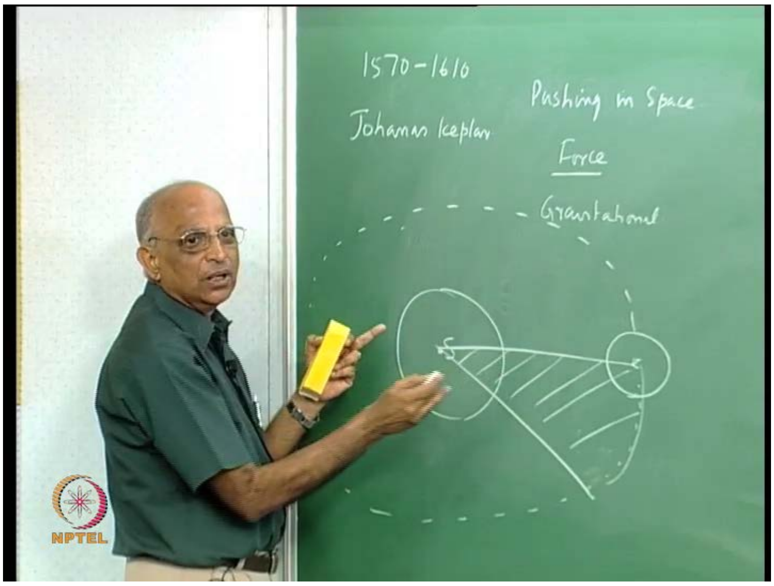

Let let let let us quickly revise through what we have done so far, we said propulsion or rocket propulsion deals with pushing in space. If you want to push in space, we need some force to push and therefore, the one of the forces which we should consider is the gravitational force.

Let us let us start with that, to be able to understand the gravitational force, it becomes necessary for us to go back into the solar system. Look at the revolution of the different planets around the sun as it where. Now let let us just see let let us just take one particular case, I take the earth here and I say it is going around the sun, may be the let say the sun is over here.

Earth is going around the sun as it where. You know people have been watching the motion of planets around the sun for years together and in may be around the year 1600 may be 1570 or so, 1570 to 1610. We had a famous person by name, Johanas keplar. He index three laws which govern the motion of planets like earth around the sun, his thing was he said there are three laws and what are the three laws.

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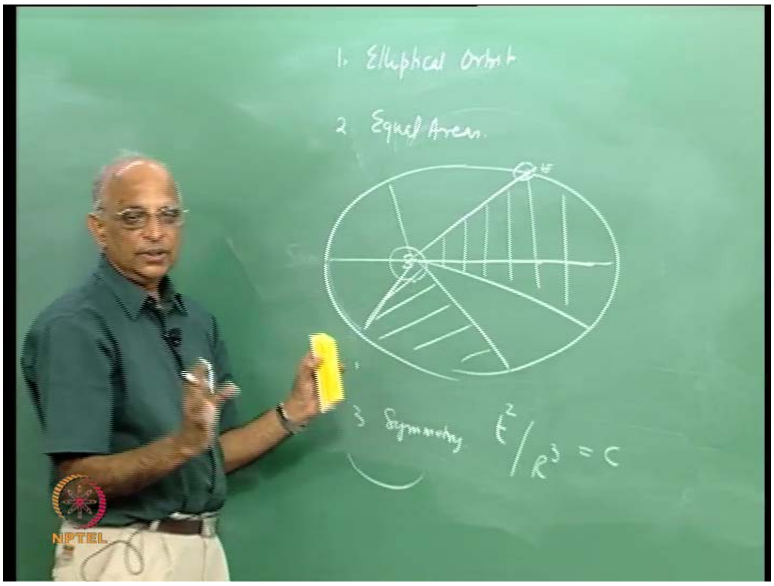

Let lets quickly get through before because it'll help us to find out what we mean by the universal law for gravitation.

He told the following, all planets move in elliptical path, have elliptical orbit. By orbit, I mean the path of the planet around the sun as it where and we are talking all the path will be elliptical. But if you read the newspapers around the month back, there was a news that the orbits are not really elliptical but they are wavy orbit something like this it is going on.

Well some work is still going on we will not get into those details but as per Johanas keplar we have the orbits in an elliptical path one. Second is he also had the second law we said something on equal areas, what is mean by equal areas. He said suppose in we have a line, in which we join in the centre of the sun with the centre of the earth. And then we find out what is the area swept during the elliptical orbit. He finds that the equal areas are swept out in equal times.

Let us just put it together the, this is the sun which is at the focus and you have something like an elliptical path. Let say this is the major axis and then you you have an elliptical path this is the second foci, you have an ellipse as it where. This is the earth going around the sun. First law says it is an elliptical path, the second law says, may be equal areas are swept out at equal times.

If this is the time taken for this this area is swept out by the imaginary line joining the centre of the earth with the centre of the sun. And similarly in an equal area will be swept out during the motion from here to here. All it tells is may be, if I come to this particular path in which the, I have minor axis.

May be, it'll travel a longer path here compared to a shorter path in this particular one is the second law for for the orbit which is given by Johanas keplar. The third is one which says about symmetry of orbits. All what it tells is you have the earth, you have may be mercury in here by, you have may be Neptune far away. It tells that the time of 1 revolution divided by the radius, is such that the orbital time t square divided by the distance cube.

That is the distance from the sun to the different planets divided by the time of orbit of the particular planet is the particular constant. These are the three laws of the orbital motion has formulated by Johanas keplar, why are we getting into orbital motion, we are just talking of space, we want something to understand something about gravitation. And therefore, you have these three laws and then comes Newton much later and what does Newton finds,

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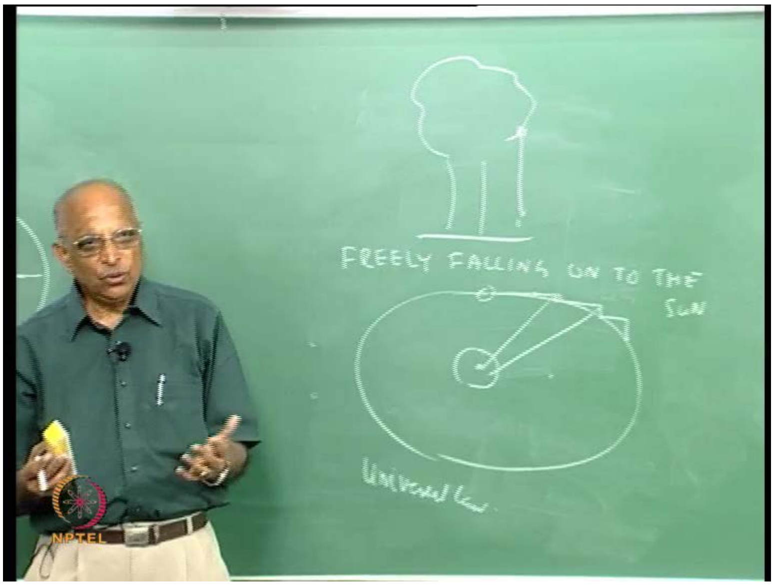

see he is he is he, that the story goes like this, may be he watching an apple fall on the ground from a tree, apple is falling. He immediately connects the apple falling from a tree to the elliptical orbits or orbital motion of the different planets around the sun. What is the commonality, how how can we what what is the common factor between these two. Let let us take a another look at it and come back to this question of what decides what is planetary motion, what we are dealing with it. Let let us let us say, this is the as it where let us say that the earth is going around the sun like this.

May be the earth is going, when the earth travels some distance like this, it falls through some distance because its elliptical. Again the earth let let say, it would had a horizontal velocity it will go like this but in the process of going horizontally, it falls through some particular distance. Again it goes through some it comes over here, again it comes like this. In another words, if I had given a horizontal velocity to the earth, it keeps on falling towards the sun at each instant of time. In another words, if the earth where to go horizontally at a velocity, it falls by a certain distance as it travels.

That means, have a constant velocity and it keeps falling therefore, its has if the earth is freely falling. It is no different from an apple which falls on to the ground. Actually, if we look at ourselves today all of us where just freely falling towards the sun. Just in the same way, as a fruit or a stone is falling from the tree. Therefore, he says well there must be some commonality between an apple falling to the ground and the planets falling towards the sun and it becomes something known as the universal law.

See, you know you know see the point is, Newton did not do the experiments himself. He did nothing to really say that, I derive the Newton the gravitational law like this, just based on observations of Johanas keplar. And ofcourse, you had one or two more people like Galileo Galilee who who as you know dropped a piece of a feather and an iron ball and found that in vacuum both of them will take the same time to come to the ground. Just based on these 2 small observations, he was able to formulate this law. But before I get into the gravitational law, its necessary for me to go into some more details like how do you measure, you know because when I say some force and all that, we must be a little more clear on what are the parameters.

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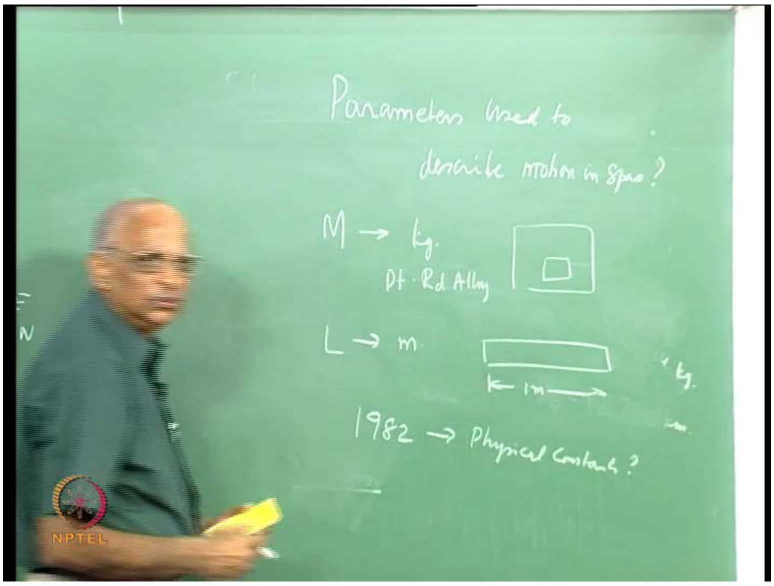

We must use, describe motion in space. I think we must be very clear because a time has come when I to put some numbers, like to put some equations. I know how to I must know how to express myself. Therefore, immediately we all say we are all engineers ,we have we know about mass, length and time. I can use these three fundamental quantities and describe it. How will you describe mass? Quantity of matter, unit is unit is kilogram well said but what is a kilogram. It is some reference kept in a lab near in severs in near paris since let say, 1819 or so some standard is kept. Its kept very carefully, you know in a decicator in under very control condition such that nothing will going to happen.

It is a platinum rhodium alloy which weighs 1 kg and it has been duplicated at different which we use as a standard. Well its accepted, this is 1 kg. So, also when I say length is in metres. What is a meter, again a reference kept at the same lab since may be last 150 year or so. And this the particular length scale which is given, the length of this standard. It’s again an exotic alloy of platinum rhodium but then there are some problems over the last 150 year, you know it is stored in a best condition, you have some duplicates in some other countries or so.

It keeps eroding, whatever be this some changes takes place. Therefore, it is not a good standard, we need a better standard. How will you have a better standard, you know therefore, what happened was in the year 1982, quite recently. People said, when I have a length standard, when I say a meter, I go and say well a meter is so long and is the length of this standard instead of doing this, can I express the length standard through physical constants, what is the constant I must use. Which so, that you know, whatever happens the length is the same, it cannot change may be after a million years the meter will still be the same.

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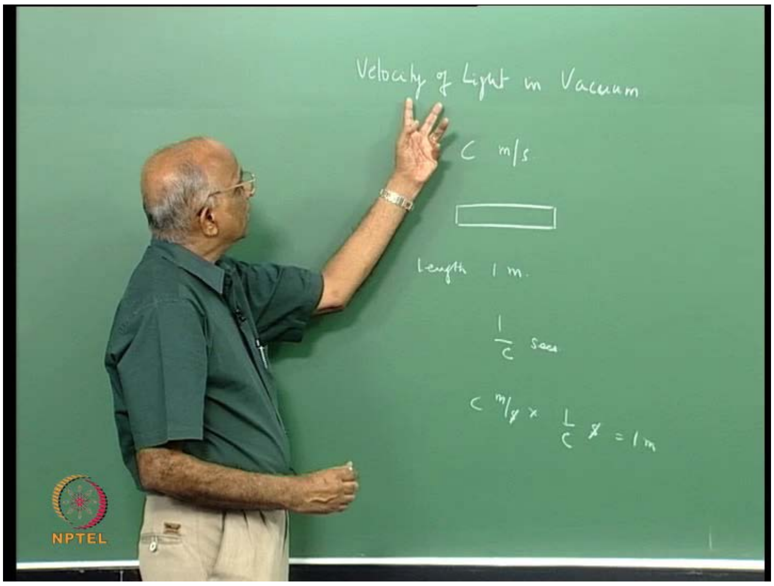

You know, the physical constant used for defining the length is velocity of light in vacuum. You know all of us know that, light is propagated as an electromagnetic waves and the speed at which the light is propagated, we say is C meters per second. The question is can we use this constant. It is a it is a constant because the electromagnetic waves propagate through vacuum at a constant speed. Let us say C meters per second and rather than define the length in terms of a standard like what we considered. A standard of so much length, which is kept near Paris.

We would like to define it with respect to this physical constant and how do we do that, well if I could have, let us say a length we are interested in the length to be defined as one meter. We say the distance travelled by light in 1 over C seconds is what constitutes 1 meter. How do we look at it, the speed of light is c meters per second, the light travels at a at a speed of c meters per second. The duration, we are considering is one over c so many seconds. Second and second get cancelled and we get one meter. Therefore, the more recent definition of length scale is with respect is, with reference to the velocity of light in vacuum which is c.The precise value of c is,

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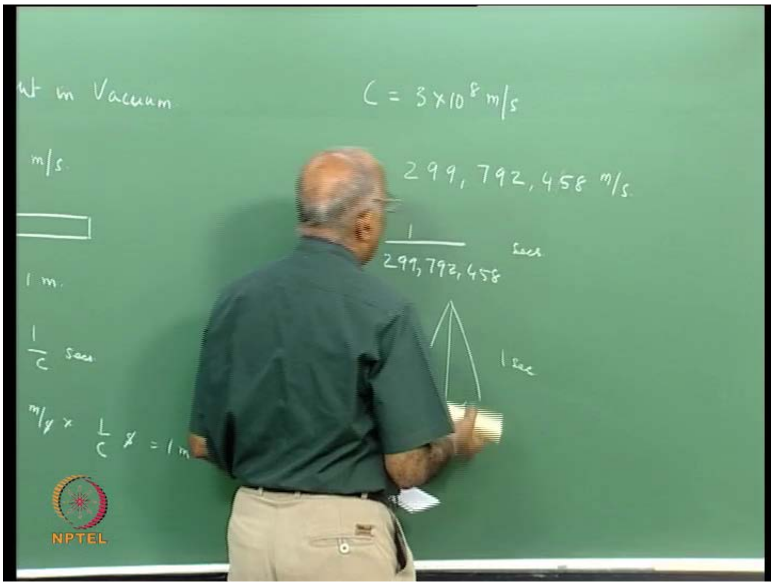

we told ourselves earlier the speed is around 3 into 10 to the power 8 meters per second. 299,792,458 meters per second. Therefore, the definition of length of one meter is the distance travelled by light in vacuum over the duration of 1 over 299,792,458 seconds. This is how we define the length scale as a meter. Therefore, what is it we have done it so far, we have considered something like the definition of mass has a standard kilogram, may be length has a standard meter but now we are telling ourselves meter corresponds to the distance travelled by light in vacuum for a duration of one over let us say 299,792,458 seconds. But then, we have still not define time.

How do we define time, we must be very clear. Time is something related the duration let us say we have a pendulum, the pendulum goes up and down. The duration of one cycle of the pendulum may be, pendulum starts here, goes here, comes back here is what we say is a duration of this pendulum which we say as one second. But then, it is difficult to have a period like a pendulum being used to describe the time scale and its its easier for us to define the time scale based on the duration of an event and which is the event

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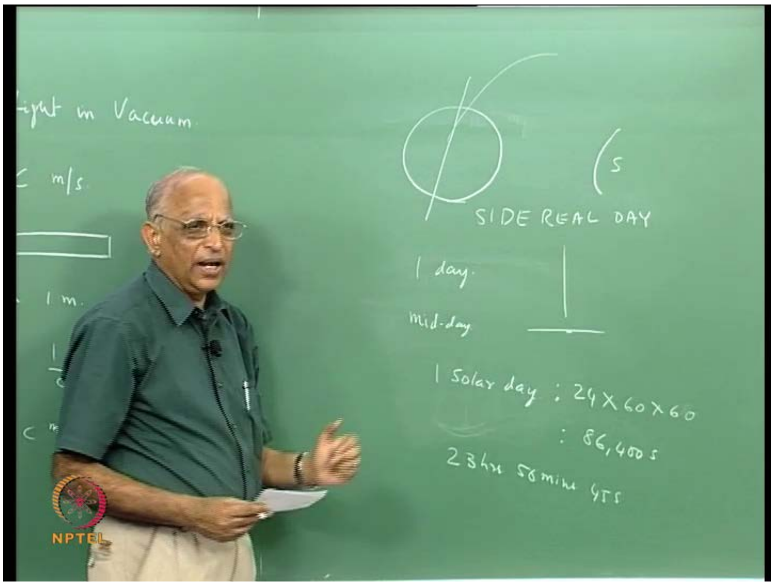

Which is most simplest to describe. We have the earth, may be revolving around its axis and it revolves, it looks at the sun. 1 revolution of the earth around its axis is what we call 1 day. May be we call mid-day middle of the day, as when sun is vertically above us. May be, the sun is vertically above the above a particular part of the earth, we call it as mid-day. And we go to the next mid-day, next time the sun is vertically above and that is corresponds to 1 period of rotation and we call it as 1 solar day . That means, in 1 solar day, a day consists of 24 hours again 24 each each hour consists of 60 minutes, it consists each minute consists 60 seconds.

And therefore, the one solar day consists of something like let us say 86400 seconds. (()) there is one problem in this, see earlier we told the earth is rotating around the sun and has it is rotating on its axis and revolving around the sun, you know the period of rotation is not exactly 1 day but is slightly shorter because it is also, as it is rotating on its axis, it's also revolving. And therefore, the exact period of of 1 rotation around the sun is not 1 solar day but it is something like instead of being 24 hours, its 23 hours 56 minutes and something like 45 seconds and this duration is what is known as a side real day.

Therefore, we have complicated day, instead of having one solar day, we said we all, we need something like a side real day which is slightly smaller than 86400 seconds but still further you know the the there are perturbations in the rotation and also in the path around it. And therefore, it is very difficult to really define time very accurately in terms of either side real day or in terms of solar day.

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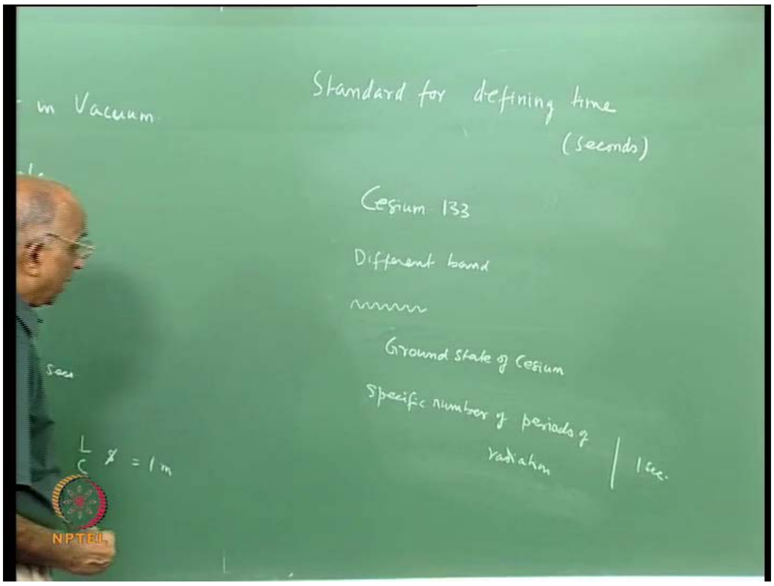

And it is really necessary to have some other standard for defining time. Therefore, the scale or the standard for defining time is defined through some other standard. Standard for defining time, that is seconds and how do we do it. May be, you know you know caesium and this caesium, we have caesium 1 3, it is an isotope element and it emits radiation. It emits radiation in different bands and what do we mean and something emits radiation. You know, may be it is emitting pockets in some wavelets and it keeps on emitting some at some frequencies and each of them is a period. So, many periods of radiation is getting emitted.

Therefore, we look at one specific band namely at the ground state of caesium. And at this ground sate of caesium, you take maybe 1 hyper fine level and you say, many number of periods which are emitted. That means, you say specific number of periods of radiation which is emitted at the ground state in this particular hyper fine level is what we will call as one second. Therefore, how how do I put this hyper fine level.

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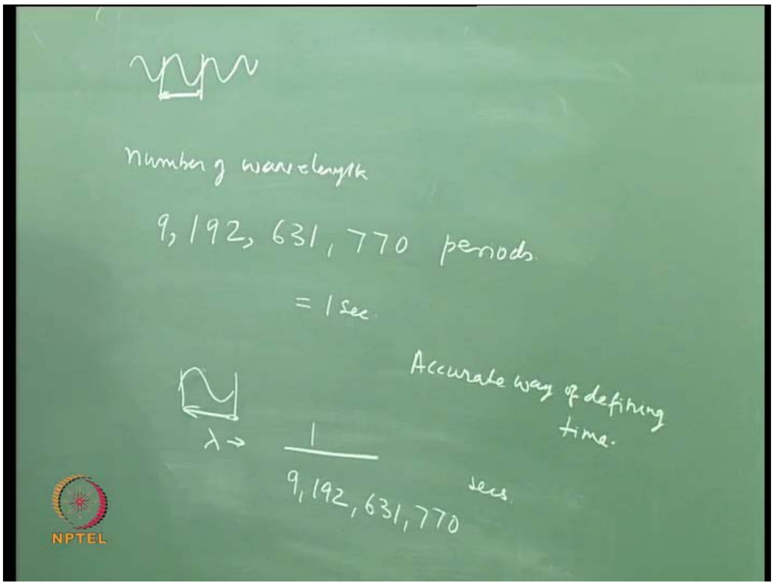

Lets again tell this, well at this ground state caesium is emitting radiation. Each wavelength from here, I go here each wavelength corresponds to have specific period. I count a large number of these wavelengths and the number of periods or the number of wavelengths, amounting to something like 9,192,631,770 periods or wavelengths. Corresponding to this ground state, at the hyper fine level is what is 1 second, what do I mean by this just to make sure we are very clear. We have 1 period of radiation or 1 wavelength, this wavelengths corresponds to a time of 1 over 9,192,631,770 seconds.

And this is how we define time, namely in this ground state of caesium the 9,192,631,770 periods of radiation emitted is what constitutes 1 second. And this is an accurate way of defining time. Therefore, what is it we have done so far, let lets quickly recap it. We have define mass as a standard, we have define length as a standard, length as a standard we said, we will define on the basis of the velocity of light. Then we said yes, we need to define seconds as the or time as the standard. And therefore, we now know yes, I have define mass, length, time.

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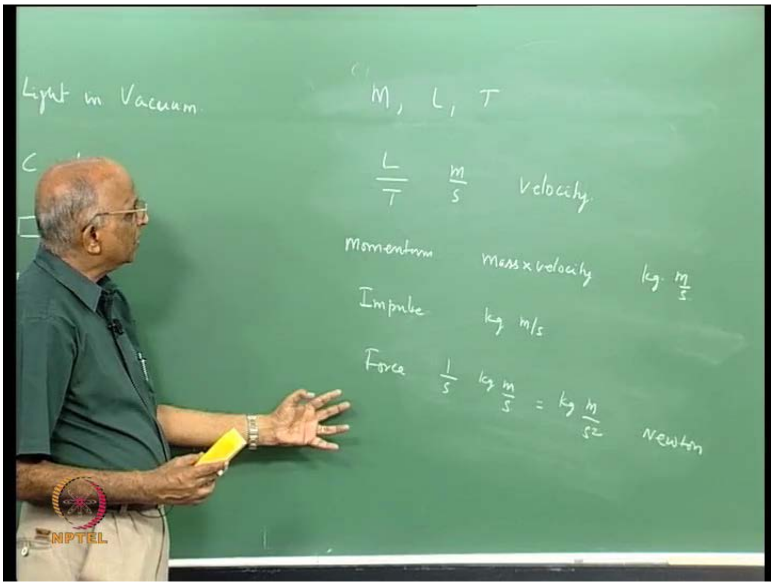

And now we can derive a set of units, the length or distance divided by time has units meter per second and this is what we call as velocity. When I say distance, distance could be a vector and therefore, velocity is a vector. And if, I say momentum, we said mass into velocity or rather the units is equal to kilogram into meter per second is becomes momentum. We say change of momentum is impulse and therefore, impulse will have units of same as momentum namely kilogram meter per second. We went forward and said that, rate of change of momentum is what constitutes force or rather the impulse divided by the time is force.

And therefore, force could be defined as rate of change of momentum, that is 1 over second into we have momentum as kilogram meter per second or rather the units of force becomes kilogram meter per second square which is what we call as Newton. Therefore, we have define through these three basic definition of mass, length and time. Velocity meter per second, momentum kilogram meter per second, impulse again kilogram meter per second and force which is kilogram meter per second square.

Having define these quantities may be its time to go forward and examine how the how we can describe using these units the motion in space of the different bodies and this is what we will do in the next class, thank you.