Select / Special Topics in Classical Mechanics

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Module No. # 07
Lecture No. # 25
Potentials Gradients Fields (iii)

Greetings, we will resume our discussion on potentials gradients and fields. And we already know the connections, we know that when you take the gradient of a potential, you get the field, we know what a gradient is, and we know how to determine it in various coordinate systems.

We have learned not to by heart the expression for the gradient in various coordinate systems. What we have learnt is, what it is in terms of physics, in terms of the physical reality. What it tells us is, how a function changes from one point to another.

So, you have got a certain scalar function, which is defined at a particular point and this function would change, when you consider a neighboring point. And therefore, at the neighboring point the value of the function will be different from what is over here, depending on the rate at which it changes from this point to the other. This rate of change would be different presumably in different directions not necessarily, but quite often it is.

When you consider the change in the value of the function, you are talking about a difference in two scalar quantities, which is also a scalar. You consider the rate of change of this quantity, so you have to divide this by the displacement between the two points. But the direction in which the displacement is considered would play a role in general and therefore, this derivative, this ratio of the change in the function to the displacement itself, this ratio remains a scalar quantity, but it has got a directional attribute. So, this is the directional derivative and it is given by the component of a certain vector in the chosen direction.

The vector whose component is this directional derivative is the gradient. So, once we know what is delta psi is when what is the nature, what is the difference in the function at two neighboring points and you know how to write the expression for the displacement vector in any coordinate system, then you can easily generate for yourself the correct expression for the gradient of a function without trying to remember it, whether it is spherical polar coordinate system or cylindrical polar coordinate system or any other coordinate system it does not matter.

Cartesian it is easiest, but in other coordinate systems also it is obviously just as easy it is as in the Cartesian coordinate system, because all you do is to find what ought to be the expression of the gradient such that it is component will give you the change in the function and the change in the function you can get from the chain rule; so, there is no mystery that is left in this. Having acquainted ourselves with these connections between potential gradients and fields, I will like to highlight today that these are exciting topics to learn about in physics.

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There is a good bit of math that goes into it; derivatives, differential calculus, vector algebra, vector calculus, all these are branches of mathematics.

Essentially, what they are addressing are physical concerns, physical properties. So, it is physics, it is the study of physical observables, the effects which are generated by interaction, evolution of various states of physical systems. These are the issues that a physicist is interested in and we find that, these are tools that become handy to investigate these physical phenomena and I will illustrate a few applications today.

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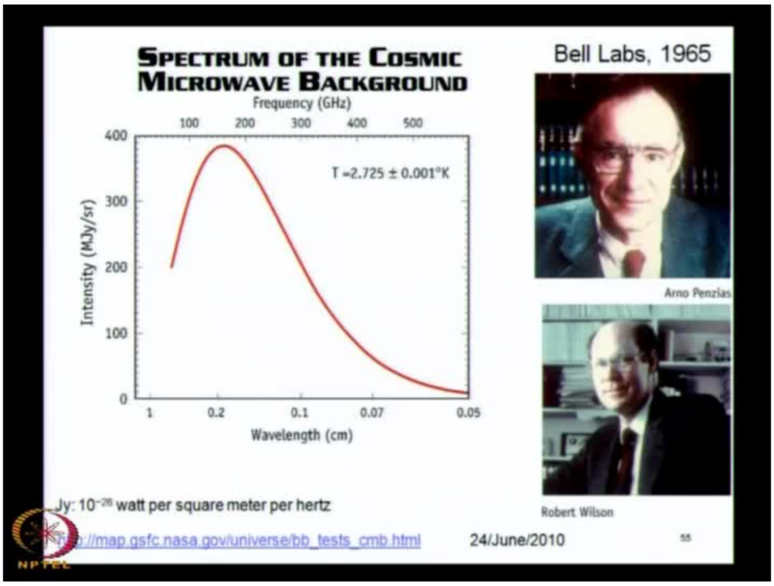

At the end of the last class, I raise this question; I brought to your notice that, a central issue in physics is what all this is about? What is this entire universe? How did it start? When did it start? I do not think we will ever be able to deal with questions like why it started, but that goes beyond the realm of the physics that I am familiar with, so I will not worry about that.

But there are fairly reliable estimates about when it started, how it started, probably by the big bang, it may not be a complete answer, but at least the beginnings of an answer. How reliable are these models? It means what is the proof that a big bang took place all about 14 billion years ago like 13.7 or whatever, or what might have happened in the first few seconds, first few minutes, first few days and months.

One of the predictions of the big bang is that, there would be this cosmic microwave background whose intensity distribution you see on this curve and this was detected by Penzias and Wilson. And it is a very weak kind of background radiation and what is really weak are the anisotropies. Is it exactly the same coming from different parts of the sky or is there any settle variation? With the temperature that you see corresponding to the intensity distribution is like a slightly less than 3 degrees kelvin, 2.725 plus or minus 0.001; so, that is the accuracy with which these measurements have been carried out.

If you want to see if there is any anisotropy, then you need to carry out very accurate measurements of the intensity distributions, from which you can then estimate the temperatures.

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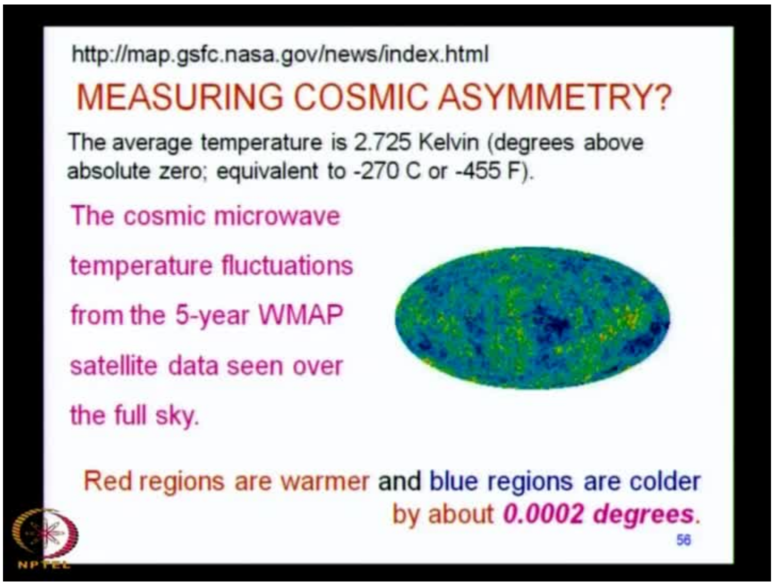

Now, here is a result of the intensity distribution or rather how it expresses itself as the temperature distribution which is recorded by a certain observatory, which is known as the Wilkinson microwave anisotropy probe. WMAP stands for the Wilkinson microwave anisotropy probe; this is a satellite, which has recorded these intensity distributions.

There is a temperature coating over here, different temperatures are indicated by different color codes, small pixels on this map. And the red regions are warmer, the blue regions are colder and the differential is something like 0.0002 degrees is very accurate information. Now, if you want to carry out observations with this level of accuracy and that is the level of accuracy in that is needed to detect, if there is any asymmetry at all in the cosmic microwave background, then you really need to place your observatory.

At some place where it will not be disturbed by noise, so if you place it on earth surface, anywhere in your back yard or wherever or on the top of a mountain, there will still be so much of noise coming, because most of the day you get sunlight over there. All your readings will get swapped off and you will never be able to detect differences of the order of 0.0002 degree and so on.

So, where will you keep this observatory? This whole question of potentials and fields becomes relevant in this context, because you must keep your observatory at some place where it is secured; it is not disturbed by noise from the sun, it can always, it should always be looking at, the observatory must always be trained at the dark side of the universe from wherever the observatory is placed.

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It is important to house your observatory, to locate it at such a point in space and one does it routinely like for various purposes. If you need a communication satellite or satellite for meteorology observatories or weather forecasting or for global positioning system, remote sensing whatever, you always choose your orbits to be something very specific, because only in certain chosen orbits would get you the best efficiency of carrying out the remote sensing or whatever observations or whatever communication the satellite is supposed to serve.

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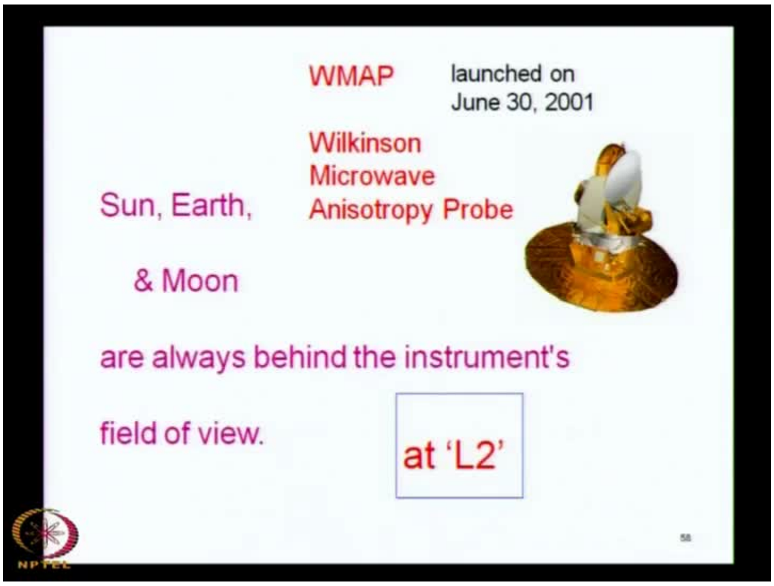

So, this Michelson Wilkinson microwave anisotropy observatory probe and here is the picture of this probe (Refer Slide Time: 11:22). This is the satellite, this was launched about 9 years ago and it was placed in such an orbit that the sun, the earth and the moon would always be behind the instrument.

Can you think of some point in space, where the sun would be behind it, the earth would be behind it, a moon would be behind it, where do you want to keep it? You agree that this would be the best location in space to carry out the observations of this kind. It is placed at a point in space which is called as L 2; L 2 is the designation of this point in space.

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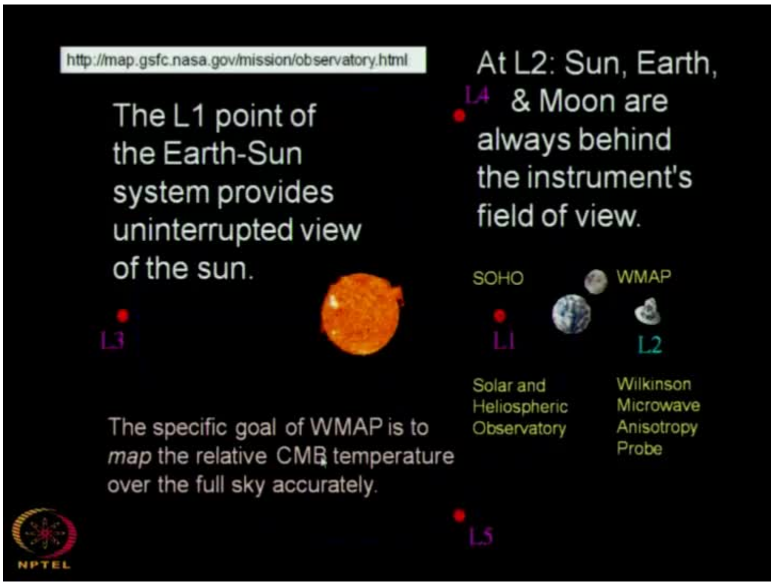

Let me tell you what this L 2 is; L 2 is one of the 5 points in space. So, this is the sun over here in the middle, you have got the earth and you have got the moon here, L 1 is here, L 2 is here, L 3 is here, L 4 is here and L 5 is here; so, there are five points in space which are rather peculiar (Refer Slide Time: 12:34). These five points are called as the Lagrange points and out of these five Lagrange points in the earth, sun, gravitational field of the earth and the sun, the relative positions of these five points remains the same. The relative position, the actual position of course would change, the earth itself revolving around the sun.

Of course, if the relative position of L 2 has to remain the same, that point should also in absolute terms must be changing, but it is relative position with regard to the earth and the sun would always be the same. If you place a satellite over here and this satellite is well beyond the orbit of the moon, and this satellite is looking, is carrying out, it is observations on the other side, Right.

The sun, the earth and the moon will always be behind it. It will not get any light from these sources, because the sun, of course, is a great and a powerful source of light in our solar system.

Anywhere else in space outside the earth, an object will receive light from the sun, but also the reflected light from the moon and also the reflected light from the earth, which will be a lot of light. But if you keep a satellite at a position like L 2, then it will not receive light from these parts and it can look at the rest of the universe.

As the earth orbits round the sun, this L 2 will also go around retaining its relative positions with respect to the earth and the sun, and it can really map the radiation coming from the rest of the universe. So, it is a great house for a satellite, which is meant for the purpose that we are having in mind. You have to locate these points and these are known as Lagrange points.

At L 1, a satellite has been launched which is known as the solar and Heliospheric observatory, because if you keep a solar observatory over here, its relative position between the earth and the sun will always remain the same; its absolute position will keep changing, because the earth itself going round the sun, but the relative position remaining invariant, this observatory will always have a view of the sun.

So, it will never be that it goes behind the earth and gets and the sun itself gets eclipsed by the earth, that will never happen; it will get a continuous picture of the sun. These are important observations to be carried out, because by looking at the sun, which is our star, we can learn so much about the universe.

So, one observatory which is called as the solar and Heliospheric observatory is placed at this point called L 1; this is the SOHO satellite. SOHO stands for solar and Heliospheric observatory and the WMAP is placed over here, which is this microwave anisotropy probe which is the one I mentioned (Refer Slide Time: 16:48). This is kept at the other Lagrange point which is L at L 2. And at this point, the sun, the earth and the moon are always behind the instruments field of view.

These are great points, there is no equivalent; you cannot have an observatory anywhere else in our solar system other than these points L 1 and L 2. To carry out the kind of observations we had in mind, if you want to watch the sun, keep the observatory at L 1; if you want to observe microwave background - cosmic microwave background, place it at L 2.

What the WMAP will be able to do - the Wilkinson microwave anisotropy probe will be able to do is, to map the relative cosmic microwave background temperature over the full scale very accurately.

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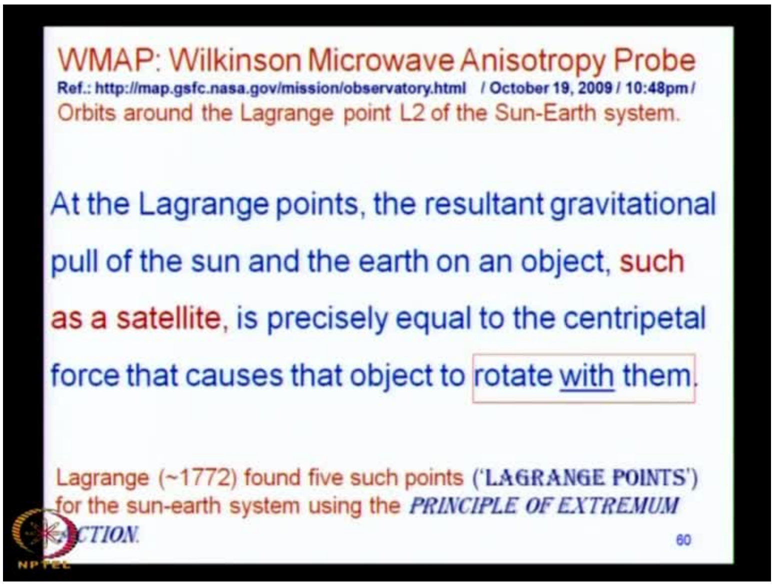

Now, what this satellite does is it orbits around the Lagrange point L 2 of the sun and the earth system. Now, the peculiar feature of this point L 2 is that there is of course, the gravitational field at any point in space, at every point in space, you cannot really switch off gravity.

You can switch off the electric interaction, but you cannot switch off gravity; there is no insulator that you can keep in between. You keep anything in between two masses, these two masses will continue to attract each other with g m 1 m 2 by r square, regardless of what is in between or around either of these two masses.

But, what you can do is the resultant gravitational pull of the sun and the earth at the point L 2 is such that, this resultant pull provides the exact centripetal acceleration that would keep an object placed at that point at the same relative orientation, so that it keeps revolving synchronously with this. So, that its relative position will remain the same and the sun, the moon and the earth will always be behind this point, that is the idea.

So, this is the point where the gravitational pull is exactly the one - the gravitational pull of what? By both the objects together, because the sun generates a gravitational field, the earth also is the source of gravitational field, any piece of mass is, every piece of mass is. The resultant gravitational pull must provide the exact centripetal accelerations, so that it revolves synchronously retaining the relative position with the two objects. And rotating with these two objects is the key feature, so that it can always have the sun, the moon and the earth behind it.

Now, these five points were identified by Lagrange using the principle of extremum action that we are familiar with, which we introduced in the first unit. He made this discovery around 1772 and these are known as the Lagrange points. He made use the principle of extremum action to discover these points.

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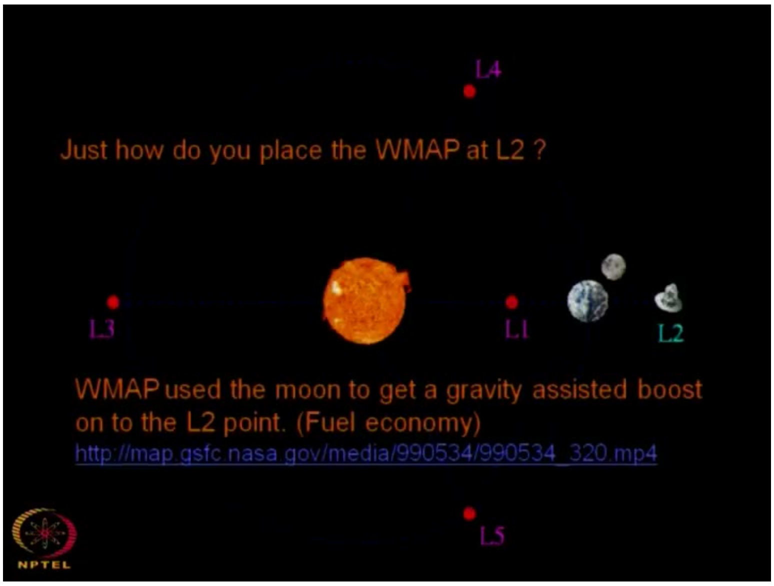

Now comes the question, we are agreed that this location L 2 will be a great place to house a satellite. How do you get a satellite launch it from earth, so that it goes and sits there?

While playing marbles, I can hardly direct it in a particular direction that I want it to go. Here, you want to assemble a satellite, set up the electronics, set up the computers, prepare the sensors, have solar panels, so that it can be energized every one so often. Put it all together, shoot it off a rocket from the earth and then ensure that it goes where I want it to go and it goes and sits happily at L 2.

Now, this is a very challenging task. What was done is to exploit the gravity of moon to provide a boost to the satellite. The satellite which was launched from the earth, it goes into an orbit. And then, it exploits the moons gravity and the moon is not static in the universe, it is revolving round the earth, the earth is revolving round the sun, very complicated system. In this, you must launch it such that at a given point of time, it comes close enough to the moon, so that the moons gravity will influence it, swing it and then send it toward the point L 2. This is a brilliant calculation and you will see how it works.

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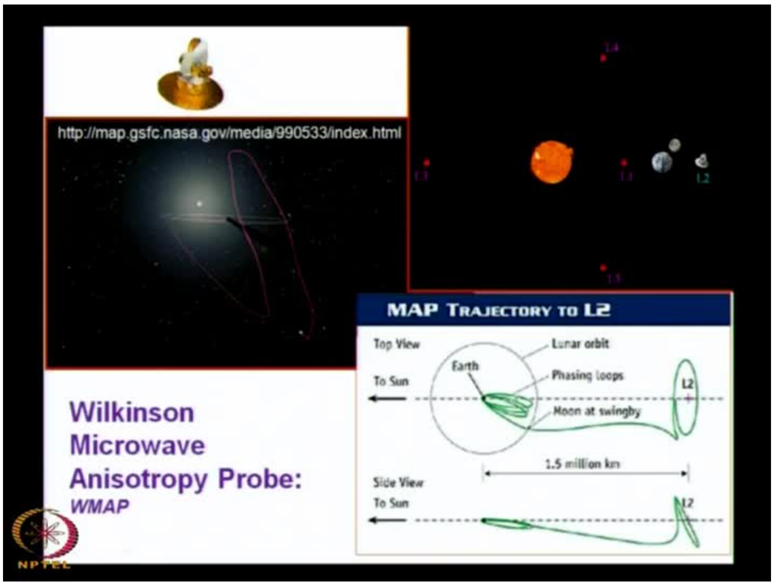

These are the trajectories (Refer Slide Time: 23:03). So, from the earth it is launched, it goes in various what are known as phasing loops and then, it goes there is a moon over here which is in the lunar orbit. This satellite finds itself close enough to the moon, which swings it, then it is launched in an orbit about the point L 2. This is the trajectory of the Wilkinson microwave anisotropy probe.

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Now, I downloaded this trajectory from the NASA website yesterday; and I will show you how it looks like. This is a small little movie which you can see and it should come up with it, I hope it does. I tried it at home, it worked and reasonably sure it will come; I guess, it is coming, there it is.

Here, it is you see how it swings? Now, the satellite is coming over here, its coming over here, it is going pass the moon, it flies by the moon and the moons gravity swings it and sends it across; you can see it again, here the satellite comes, goes, pass the moon and the moons gravity swings it.

Now, to be able to do that, you should know the exact gravitational potentials at various points in space. How these potentials change from one point to the neighboring point? Because the satellite is going to swing exactly in the direction of the gradient, as it is the gradient which will generate the acceleration. It will generate, it will change the momentum of the satellite, so that it gets accelerated, it changes its speed, it changes its direction, may be both, but the change should be exactly such that you exploit the gravity of the moon, so that it goes towards the point L 2.

Now, there are many reasons and I chose to show this, because I think it is very exciting to see, how one can really make the gradient operator work for you and how the study of the scalar fields. Now, we are no more talking about math.

We are talking about observations, we are talking about satellites, we are talking about cosmic microwave background, we are talking about the origin of the universe and now all this is physics. To be able to carry out these observations, what you need to do is to have a good idea of what the scalar fields are, what the corresponding vector fields are, when you take the gradients of those fields, so that you carry out these observations.

So, this is how the satellite comes, it flies by the moon, goes past it and then you can house it in an orbit around the point L 2. At the point L 2, it will carry out the observations. This is how it goes.

Once your eyes get used to what you are seeing on the screen, you will notice that in relation to sun and the earth, the orbit of the satellite of the WMAP is always in the shadow of the earth which means that the earth, the moon and the sun will always be behind it, this is the idea.

The earth is going round the sun, no doubt, but the shadow rotating and the point L 2 remains in the shadow, because its relative position with respect to the earth and the sun remains invariant. So, these are called as the Lagrange points and these are special points of a two body problems; so, there are Lagrange points for the sun and the earth; there are Lagrange points also for the earth and the moon.

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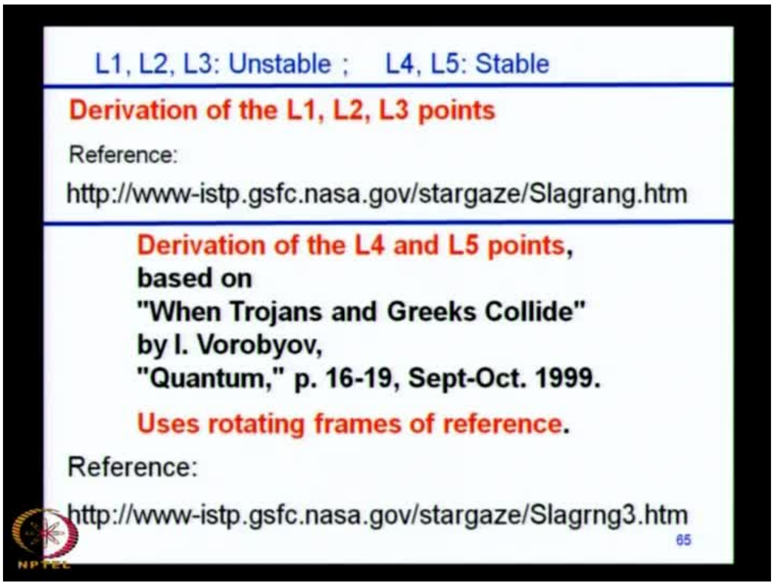

It is rather fascinating that, one can identify these points; you can actually derive the exact location of these points. The derivation is complicated, I am not going to discuss it in this class, but there are some references which you can get to from the NASA website or through this article by making use of rotating frames of references.

And you can get these links and then go through the derivation by yourself, but that is not central to the discussion over here; what is central to the discussion? So far as our immediate context is concerned is that it is important to understand, how the gravitational potentials change from point to point, how their gradients would give you the directions in which the forces would act, the forces the negative gradient of potential. And then, use this to carryout physical observations.

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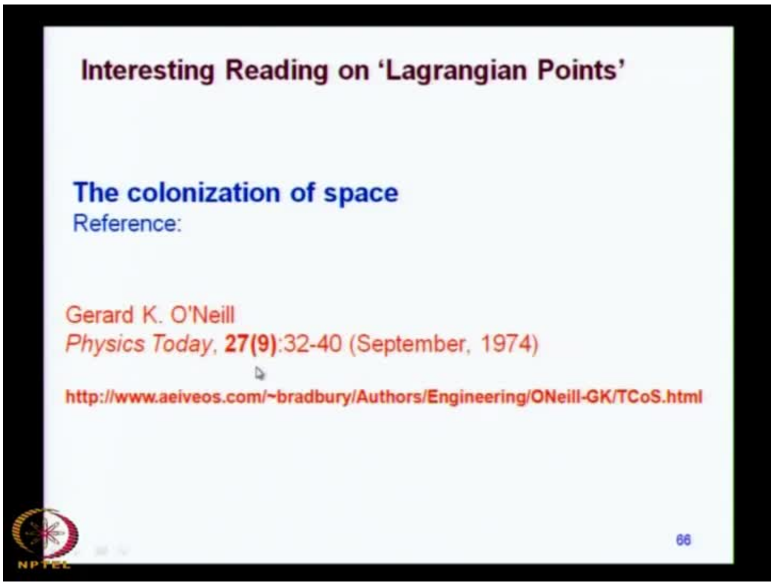

You can read a very interesting article in physics today in 1974 written by O'Neill. This article, if you just Google Gerard K O'Neill's article in physics today, you will get the full reference.

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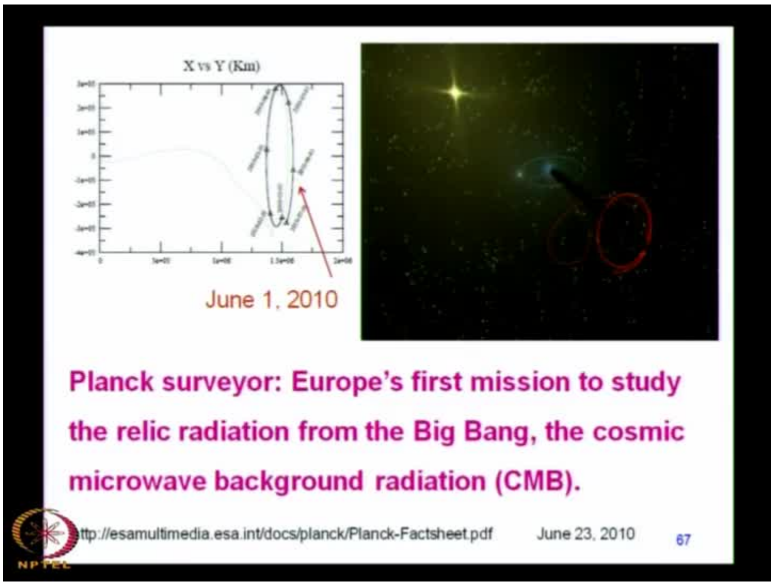

There are other probes, the WMAP was launched by NASA; there is another probe which is launched by NASA as well as European space agency the E S A. This probe is named after max Planck, this is the Planck surveyor. You can actually means this is in a similar orbit like the WMAP about the point L 2. And there are very exciting websites which give you the real time positions of these satellites, so you know exactly what it is doing today.

Here for example, just few weeks ago, on June first 2010, the satellite was over here and you can actually get detailed information. So, these are very exciting observations and experiments which are being carried out and they all depend on the exact maps of the scalar fields, the potentials and the gradients, which are crucial to carry out these measurements.

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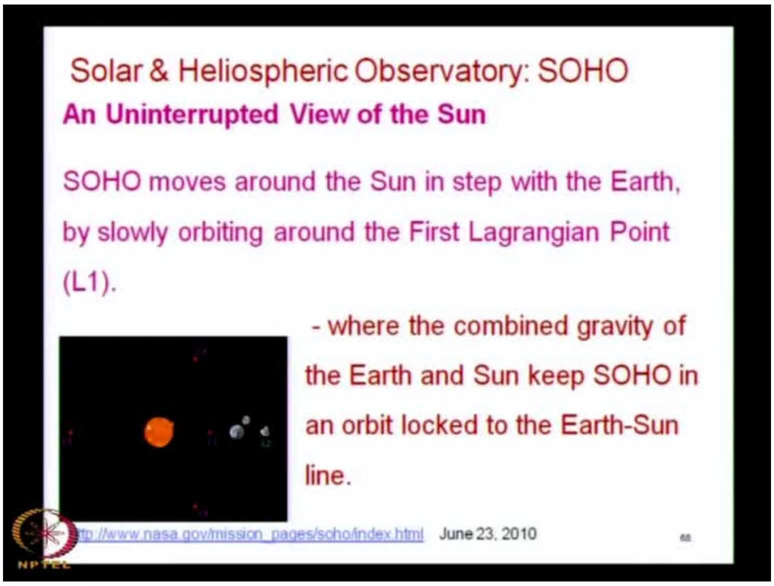

I mentioned earlier, the SOHO, which is the solar and Heliospheric observatory. It is between the earth and the sun, which is where it is today, which is where it was yesterday, which is where it was 3 months ago, which is where it will be 4 months later. No matter which season we are talking about it, it will always be there between; its relative position with respect to the earth and the sun will never change.

So, for us to carry out observations of the sun, that is the best location. This is the first Lagrangian point called the L 1. And L 1 is over here, it is between the sun and the earth, it is such a point where the combined effect of the earth and the sun keeps the SOHO satellite in an orbit which is locked, which remains synchronous. So far as the relative positions are concerned, it always remains like no matters which season, which day or which part of the year we are talking about.

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SOHO has been able to carry out some great observations. It has discovered lots of comets, because it gets a very good view where the sun is very bright and shines light. So, anything coming close enough to the sun and there are certain fragments known as the Kreutz group. SOHO has discovered a large number of such comets or fragments of the comets.

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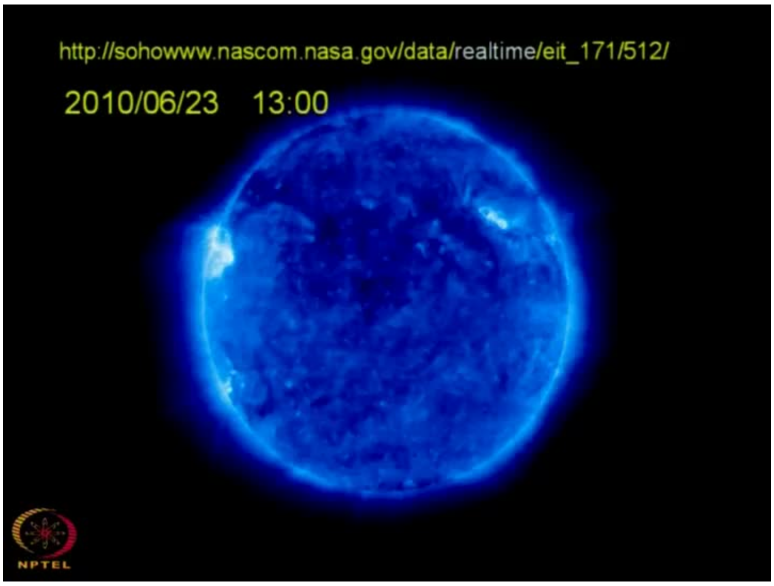

This is the picture of the sun taken by SOHO yesterday. I downloaded this image from the NASA website only this morning.

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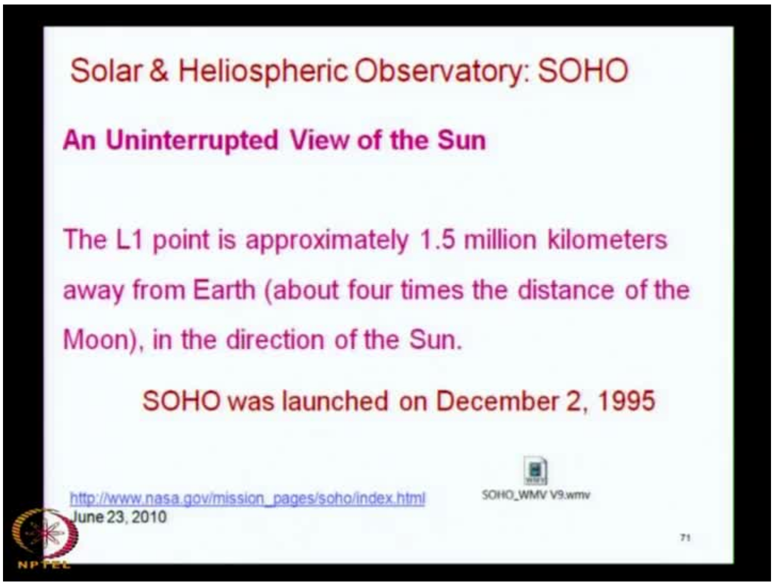

What enables you to do this is, get an uninterrupted view of the sun. So, this satellite was launched in 1995, 15 years ago; it is approximately 4 times the distance to the moon.

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It gives us these images of the sun. This image I downloaded this morning and it refers to an article which was published in the new scientist just two days ago, on June 22 in an article by Stuart Clark. What they have observed is that the sunspots which are very well known, they seem to be disappearing.

That may be an indication of something, very special, very peculiar happening in the solar atmosphere. You see how important these observations are, to our understanding of the solar system, to our understanding of our own galaxy, to our understanding of the universe. And to be able to carry out these observations, you really need very accurate, sensitive measurement devices. These cannot be located at arbitrary points in space on earth or even in orbits around the earth.

There are very special locations in the sky, in the universe and these are the Lagrange points where you can place these orbits. And it is for the identification of these points, that one really needs a very good and thorough understanding of subjects like, what is the scalar field, what is the vector field, how do you get the vector field from the scalar field, how do you get the gradients, which coordinate system is the most appropriate one, how do you carry out transformations from one coordinate system to another?

All these issues should take away from your mind that this is just math, it is not; it is physics, it is observations, it is discovering the laws of nature.

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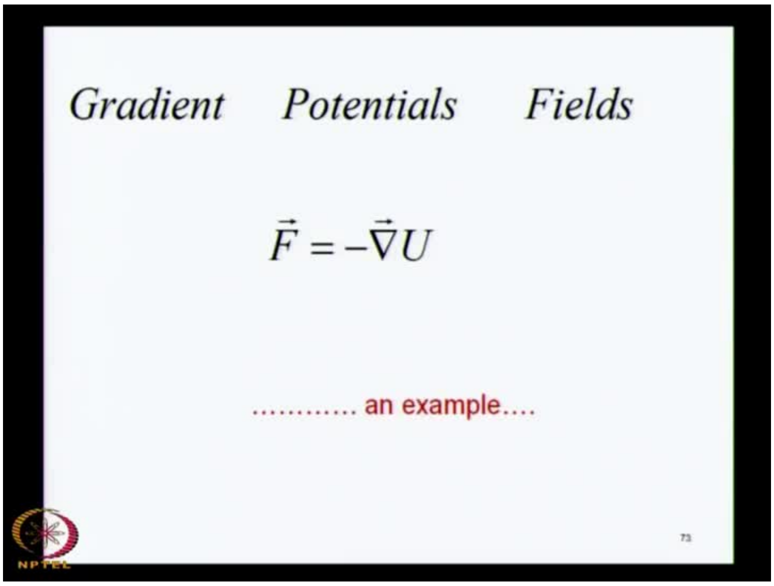

So, let us see some connections we have established between the gradients and the potentials. I will illustrate this by one example.

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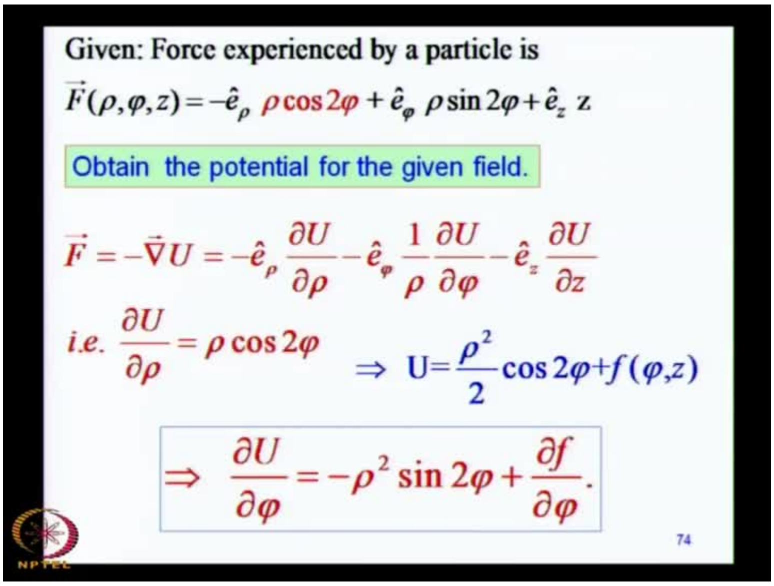

If you are given a force, which is this (Refer Slide Time: 36:09) and you are asked to determine the potential for the given field. You are given a force and this is described in the cylindrical polar coordinate system, so it is arguments are rho, the radial distance from the axis of the cylindrical polar coordinate system, phi is the azimuthal angle with respect to the z x plane, z is the distance from the x y plane.

This is the description of the cylindrical polar coordinate system and this force has got a component along the unit vector, e rho e phi and e z. The components are given to be as, we have written them out in this expression. Our question is how do we determine the potential for a given field?

We do know that the force is related to the potential, through this relation that, the force is the negative gradient of the potential. Therefore, it is cylindrical polar components are minus e rho del U by del rho along e rho minus e phi 1 over rho del U by del phi along e phi and minus del U by del z along e z.

We already agreed that we are not going to memorize this. We already agreed that we can get this expression for the gradient in the cylindrical polar coordinate system very easily. By simply requiring that, the component of the gradient of the scalar field in any direction will give you the directional derivative in that direction.

By making this simple requirement, we can always find what must be the correct and appropriate expression for the gradient in any coordinate system. So, now, there is a one to one correspondence between these relations which is the force field, which we are considering. This is the general relation between the force and the negative gradient of a potential.

Then, you know that this component del U by del rho must be equal to this component rho cos 2 phi, there is a minus sign here as well as here. So, you know how the potential changes with rho and if you integrate this with respect to rho, you get rho square by 2 from the integral of rho. Cos 2 phi is just a multiplying factor so far as integration with respect to rho is concerned. But then, there is another constant of integration which cannot depend on rho, it does not prevent it from depending on anything else.

So, this constant of integration, I have written as F; it is constant with respect to rho, but not necessarily with respect to phi and z. It may depend on phi and z, it may not, but something for us to find out.

We get some idea about the potential. This is our question: obtain the potential for a given field. We already have found the potential, but we have found it in terms of rho and phi, but also in terms of f. We do not know yet, what is the functional dependence on phi and z. So, once we find that out, we would have pin down the potential exactly.

So, we have done the problem, but not fully. We get some idea about the potential and we exploit this information that we have got so far, that this potential is a function of rho and phi. We ask what should be it is phi dependence. We had find that the rate of change of this potential with respect to phi, so that we get easily from this, because the derivative of cos 2 phi with respect to phi gives you sine 2 phi times 2. The 2 would cancel this 2, you get a minus sign; when you take the derivative of the cosine, so you get a minus rho square sine 2 phi and then you have the derivative of f with respect to phi.

So, we get the phi dependence of U, but not just in terms of rho and phi, but also in terms of the rate of change of f with respect to phi. We do not know yet, what this function f is, so we have go further and find out what is this function of f and phi.

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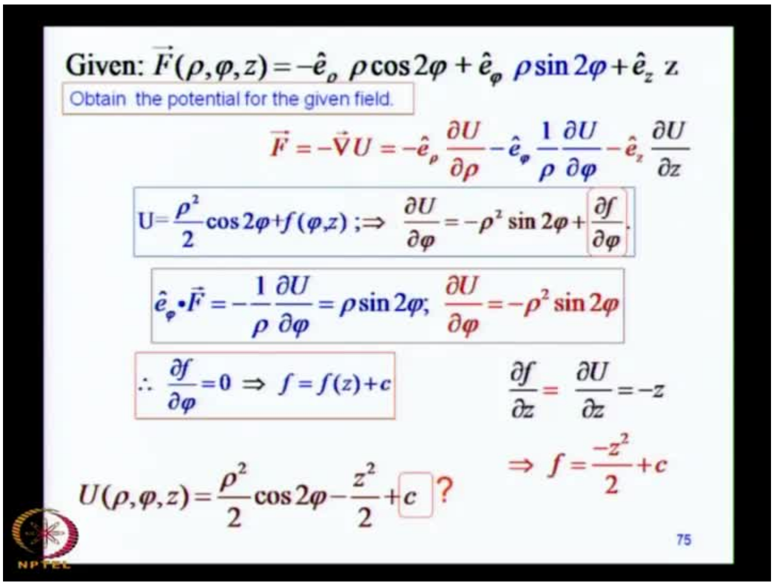

We used whatever we know so far, we know that del U by del phi is given by this function of rho and phi, but also an unknown quantity which we are yet to find.

Let us find this out and we find it out quite easily, because you do know that the component of the force along the e phi unit vector. This is something that we know, because we know what the force field is and this component of the force along e phi is essentially rho time’s sin 2 phi; this is given to us. It is not an unknown for us. We know this component and this component must be exactly equal to the component of the negative gradient of the potential.

So, we know that minus 1 over rho del U by del phi is exactly equal to rho times sin 2 phi; this is what the component of the force along the unit vector e phi is concerned. And if you just take this minus sign to the right hand side and also the rho, you get del U del phi equal to minus rho square sine 2 phi, that tells us how U changes with phi, because you can integrate this and get U is the function of phi.

Earlier, you found how U depends on rho, but you do not know yet, how U depends on phi and you can get it by integrating this equation. So, let us do that, what we know from here is the del U by del phi is minus rho square sine 2 phi. What you know from here is that del U by del phi is minus rho square sine 2 phi. If you compare these two equations, you find that this del f by del phi must be necessarily 0.

If you integrate phi with respect to f with respect to phi, it can only be a function of z and a constant. Now, you have del f by del z, which must be equal to del U by del z, because this is your expression for U. U is this function of rho and phi, z does not appear anywhere over here. So, when you take the derivative of U with respect to z, this term would be constant with respect to z and del U by del z is exactly equal to del f by del z.

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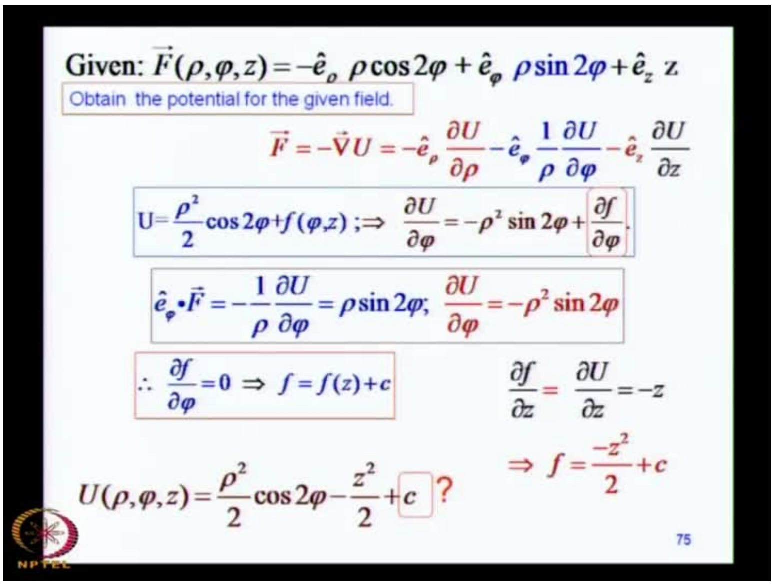

But you know what del U by del z is, because this is the z component of the negative gradient of the potential which is already given to us; it is exactly equal to z. So, there is a minus sign over here, so we know that del f by del z is equal to del U by del z which is equal to this minus times z. Now, you know how U changes with z or how f changes with z which is the same; the rate of change is the same. So, if you integrate this, you get minus z square by 2 plus a constant.

Now, you are found of function f which we did not know yet, that has now been found and you can write your complete expression for the potential in terms of rho, phi and z. The dependence on rho is through this rho square by 2, the dependence on phi is through this cosine 2 phi term, and the dependence on z is quadratic minus z square by 2 and then there is a constant of integration.

What is this constant of integration? We know that when you take the derivative of a constant, it vanishes; a constant is a constant in a certain context. Like a function, z square over 2 is a function of z obviously, but it is not a function of phi and rho; so with respect to phi and rho, it is a constant. Here, in addition to this, you have got a constant c which does not depend on rho, does not depend on phi and does not depend on z either.

This is something which sticks into a potential, it is somewhat similar to this. That if you find out what is the gravitational potential energy of this bottle of a certain test mass that I can hold over here, you would say it is like m g h; the well-known formula I do not want to tell you, what is m, what is g and what is h. I am sorry, I think I have to tell you what is h, because h is a certain height and height with respect to what? From the top of this table, from the floor, from the ground floor, we are now sitting on the third floor of this building, what about the bottom of a well or from the top of the terrace? It does not matter if I am interested in asking myself, how the equilibrium of this object will change if I let go.

I am holding it if I let go, then regardless of what my base was, whether I measure the height from the top of the table or from the bottom of the ground floor or the top of the terrace. I can tell you that this bottle will be accelerated at 9.8 meters per second per second.

What the base level was, where I kept the 0 of the potential would not really matter. So, the choice of the 0 of the potential is a constant, that I can add to the potential or subtract if you like, because I can measure the height also from the top of the terrace and subtract it.

It is irrelevant to the physics, it is irrelevant to the dynamics, but it is relevant to the potential, because the value of the potential is as you see in this expression; it is rho square by 2 cosine 2 phi minus z square by 2 plus c. So, whatever is the exact value of c must appear in the potential, but it will not show up in the gradients because the derivative of a constant vanishes.

So, this is something that you can choose and this is like choosing a measurement scale where do you keep the 0 of your scale or if you are measuring the thickness of metal sheets, you use what you call as gauge. This is like choosing a gauge and you can get the same physics even if you carry out certain gauge transformations.

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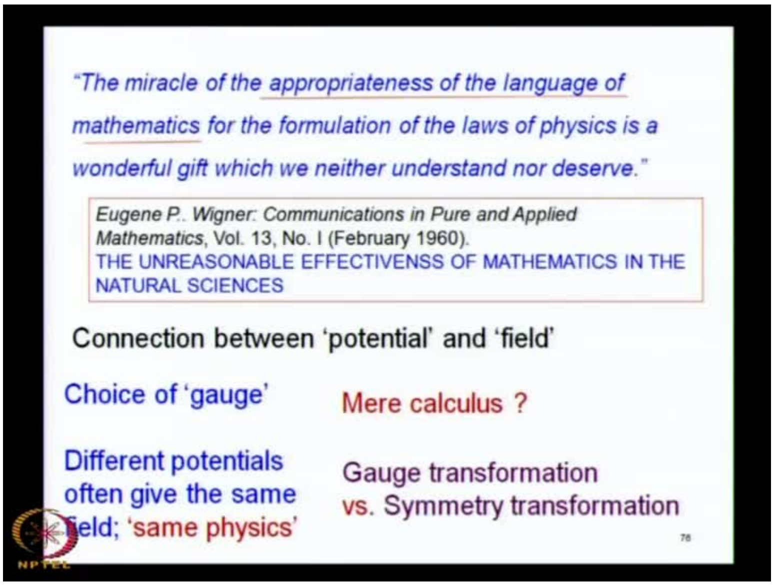

So, it is interesting that you have these connections between mathematics and physics. This constant c is coming from mathematics, because the gradient of a constant function is 0; the derivative of a constant is 0, it is coming from the mathematics, and it is coming from the choice of the gauge.

It is not appearing explicitly in the physics, it is not appearing explicitly in dynamics and it reminds me of Wigner's coat which we had towards the beginning of this unit, that the miracle of the appropriateness of the language of mathematics for the formulation of the laws of physics is the wonderful gift which we neither understand nor deserve.

But then, we do understand it to a fair extent and I think the brilliant work of people like Wigner guarantees that mankind deserves it, because Wigner is the product of mankind. So, to a large extent, we deserve it because these are discoveries made by people - not ordinary people like many of us, but certainly by people like Wigner and the likes.

So, now is this just mathematics, we find that mathematics appears in a very intimate fashion. In the expression for the potential and the field, when you differentiate the potential, you get the field; when you integrate the field, you get the potential, but you get a constant of integration from math, which does not appear in your dynamics, which does not appear in the physics. So, it is just a matter of calculus or is that more to it and these are rather certain questions because in certain situations, the gauge does become important.

By large you have different potentials which give the same field or the same physics; this becomes this is very well known in electrodynamics. I will comment on this, when we discussed gauge transformations in electrodynamics in a later unit.

But, there is more to it than just math, there is more to it than just calculus. So, gauge transformations allow you to carry out transformations from one potential field to another, one potential function choice to another, but you can get the same field equations, but this is not the same thing like symmetry transformations.

Symmetry transformations are connected with this invariance; gauge transformations give you new potentials which give you the same physics, which give you the same fields. These are just mathematical transformations, but in certain situations and the connections become more important, when you do quantum theory in which the potentials really require a very specific meaning even in classical mechanics in certain cases.

There are examples in classical mechanics and quantum mechanics like the Aharonov-Bohm effect or berry phase in quantum theory etcetera in which these issues become quite subtle and important.

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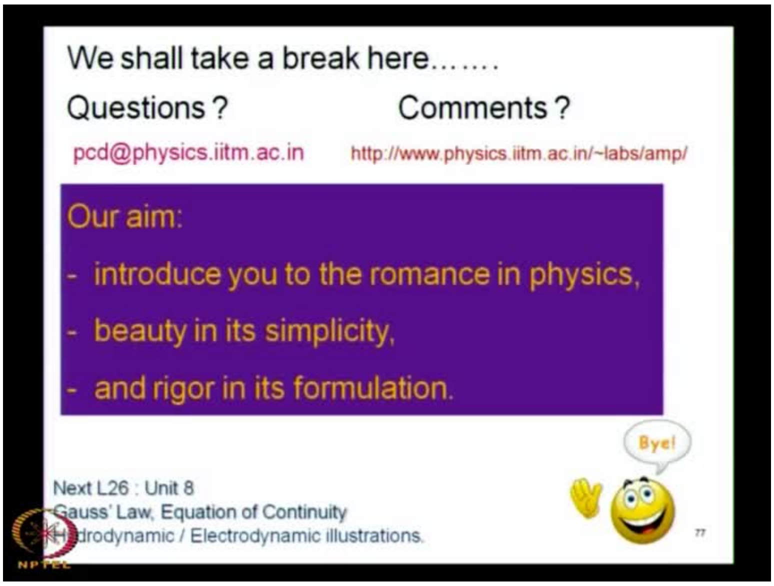

So, I will take a break here. I hope you see in this analysis, you developed an understanding the laws of nature, these are the regularities. That by law, you cannot predict what is going to happen, but certain things can be predict. What can be predicted under identical circumstances are the laws of nature.

I think this is what makes physics a romantic that with all the uncertainties about the future, there are certain things you predict if you let go this bottle, you can predict precisely that it will get accelerated at 9.8 meters per second. So, that is predictable and that is amazing; so, this is the law of nature.

It finds its expression in very rigorous quantitative and mathematical forms but, it is still very simple and I hope that we get some acquaintance and we learn to use mathematical quantities like gradients, fields, start using vector calculus.

Not merely as creations of a mathematical mind, but not just as useful tools but as beautiful tools. Lovely tools which give us a good handle on how the laws of nature are to be interpreted how we understand fields, how you can tell that a point on a surface belongs to an equipotential surface and if it belongs to an equipotential surface an object at that point will continue to move only by it is initial conditions by its inertia.

If it is to change its rate of equilibrium, then it should come only from the gradient. So, these are some other things that we learn from this. I will take a break here; if there are any questions, I will be happy to take. I think I had a movie of the SOHO orbit also, which I think I skipped. Let me see if I can get it.

Now, this is the SOHO track. This is the sun, this is the earth, this moon is orbiting this earth, this is the lunar orbit, but SOHO is always between the earth and the sun. This is at L 1, is it not amazing?

Have you seen how important these observations are? What I showed you is a picture taken by SOHO yesterday. And you can get these pictures in real time on many of these websites, so if you go to NASA website or if you just Google SOHO, you will easily find it, you can get real time images. And you know what are the current issues, you know that today’s big story is that the solar spots, the sunspots seem to be disappearing and that is perhaps a suggestion that something is happening in the heart of the sun or the stomach of the sun or whatever you want to call it.

These hearts and lungs and stomachs are our parts, not the suns part, but anyway what is happening inside the sun and you know that some big things are happening. By studying this, we are going to get some clues about how stars evolved, how galaxies evolved, how the universe is evolved and could we have got this information without the SOHO which is kept at this particular place.

Alright, so thank you very much. I guess we will stop here and we are meeting next for unit 8, which will be on the Gauss law, equation of continuity hydrodynamics, electrodynamics and so on.