**Elements of Solar Energy Conversion**
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**Lecture – 04**

Hello. Welcome back. Today we are going to go into the 4th lecture of this series.

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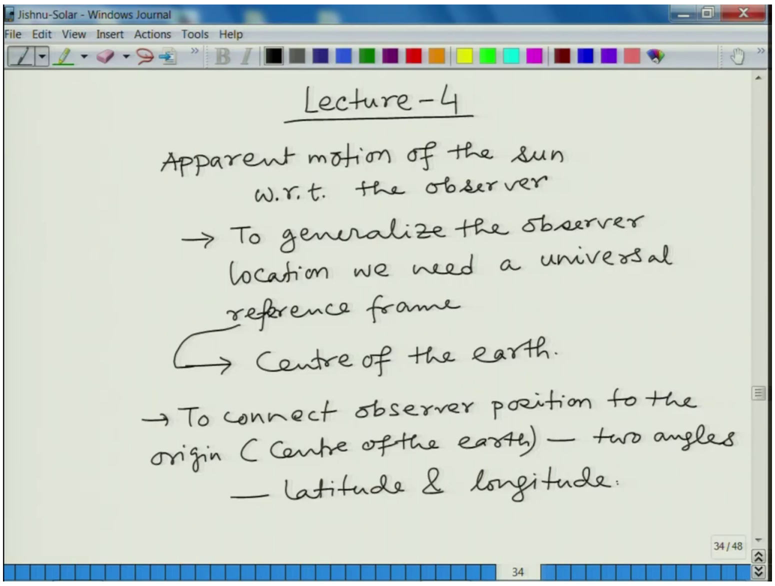

So, we will start lecture number 4 ok. So, far we have built up little bit of background, which is most often the recapitulation of what you already know from your schooling days ok. But we need to look at them more critically now because we are going to use those information and knowledge into actually calculating few things. So, please give your attention and try to visualize all those things that we are discussing in the class ok.

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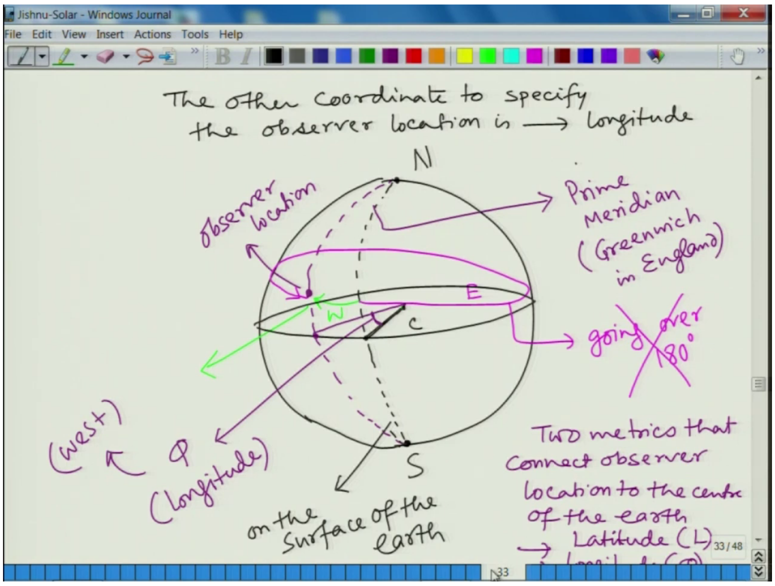

So, last time we were looking at the relationship between the sun, earth, the observer and the center of the earth ok. So the critical information that we need is the apparent motion of the sun with respect to I am just abbreviating it with w r t with respect to the observer ok, observer. So, that is the critical information because observer is the point where we are going to place our solar energy conversion device; whether it is a photovoltaic panel, whether it is a reflector, whether it is a concentrator.

So, that is the point where we are going to put our conversion device, so, the apparent motion of the sun with respect to that point is critical ok. Now to generalize this thing, the observer location we need a universal reference frame right. And in the last class we have seen that universal reference frame for us is the center of the earth ok.

So this universal reference frame is the center of the earth. So, with respect to that, we have seen that to connect observer position to the origin, which is the center of the earth, we needed two angels ok. Two angles because it is a 3 dimensional frame, so, you need at least two independent variables. So, two angels we needed; one was latitude and the other one was longitude, right. This we have seen and we have seen what do they mean how to measure it and all those things.

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→ Connection betn. the sun rays and the centre of the earth.

→ Declination angle ($\delta$)

→ The angle that the sunray which is $\perp^r$ to the surface of the earth makes with the equitorial plane

→ Observer to the centre of the earth

→ Latitude

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Now the other component of this puzzle is the connection between the sunrays and the center of the earth ok. So, here we have seen that again we will be having two angles which will connect observer sun rays and everything to the center of the earth. So, those two angle where; one was the declination angle which is often designated with delta ok.

And we have seen what it means. It means that the angle that the sunray which is perpendicular to the surface of the earth ok. The angle that the sunray which is perpendicular to the surface of the earth makes with the equatorial plane that is the declination angle.

So it does not depend on where the observer is. It just depends on what is the relative position of the sun with respect to the earth ok. So, that is a very critical angle that we are going to look into detail today, ok. The other point that we discussed, which connects to the observer to the center of the earth in the same figure we have shown you the angle that is the latitude and that figure was this one ok.

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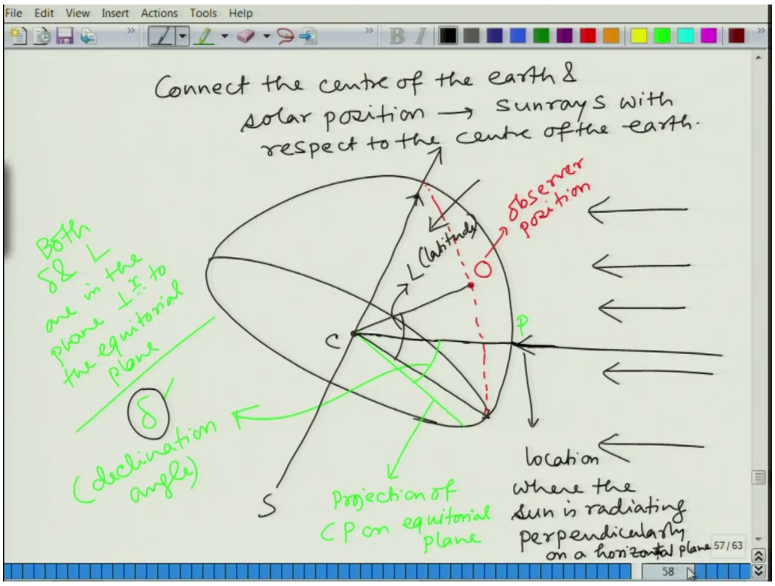
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Connect the centre of the earth & solar position → sunrays with respect to the centre of the earth.
observer position
O
L (latitude)
C
P
S
Both δ & L are in the plane ⊥r to the equitorial plane
δ
(declination angle)
Projection of CP on equitorial plane
location where the sun is radiating perpendicularly on a horizontal plane
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Here you can see that this is the normal ray that is coming and the angle it is making is called the declination angle ok. And the other angle that we have seen in the same figure that is the latitude. This is the latitude that we have seen.

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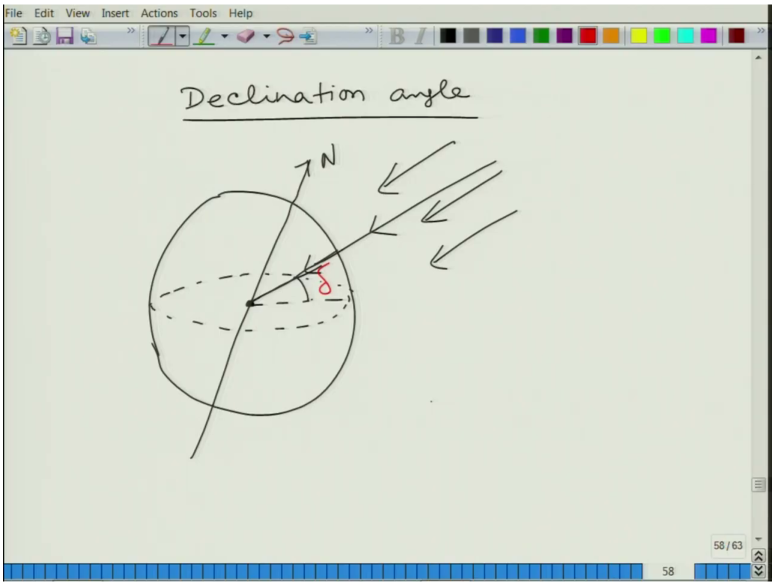

Now we are going to talk more about the declination angle ok. Because that is a very critical piece of information. So, let me draw this figure again, a little bit simplified version of it. So let us say that we have the axis like this and this is the center of the earth. We have the equatorial plane like this ok.

And suppose the sunrays are coming from this direction ok. So, the one that is actually radiating perpendicular to the surface of the earth; that is actually connecting to the center of the earth, which is this one. And what angle it makes that is our declination angle right. Let me use a different color to highlight this, so, this is our declination angle. Now if we think of it in terms of the earth position in its orbit, then let me go to the next page.

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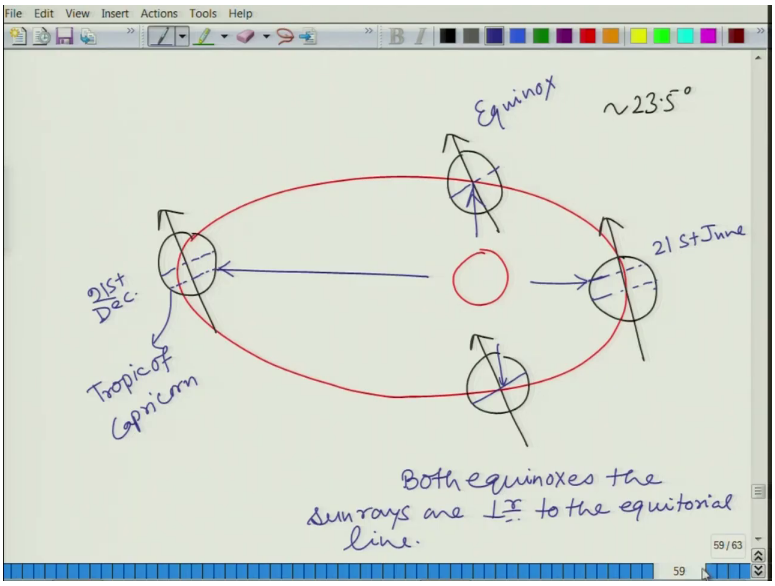

So, we have seen that if this is our orbit of the earth and if here is our sun, actually, sun should be here, yeah. In one of the far side and the position of earth or rather the position of axis of the rotation of earth, it changes right.

The angle between the axis and the orbital plane stays the same, it is approximately 23 and half degrees, but for any particular time of the year you have different declination angle right. Because, here you can see, let us say two extremes.

So, here we have seen that if this is our sorry, if this is the equatorial plane which will be perpendicular to the axis ok. Then we have seen on 21st June, the sunrays will come normal to this particular plane, which is the Tropic of Cancer. And on the other hand, if it is 31st December, I am sorry, it is 21st, 21st December, then the normal point would lie here. That is the Tropic of Capricorn ok.

And for these equinoxes we will have that the rays are actually falling directly onto this equatorial plane. So, for both the equinoxes; both equinoxes, the sunrays are perpendicular to the equatorial line itself ok.

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$\delta \rightarrow$ changes with the time of the year

on equinoxes $\longrightarrow$ equitorial line

$\longrightarrow$ $\delta = 0$ at the equinoxes.

Summer Solstice (Northern hemisphere summer)

$\longrightarrow$ Sun radiates normally on tropic of Cancer ($\sim 23.5^\circ$ N)

$\delta \sim 23.5^\circ$ North $\rightarrow$ positive

$+23.5^\circ$

Winter Solstice $\longrightarrow$ on the tropic of Capricorn

$\longrightarrow$ $\delta \sim -23.5^\circ$.

(*) $\delta$ does <u>not</u> depend on the observer position

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So, from this picture what you can understand that this declination angle it first it changes with the time of the year ok. And on equinoxes sun radiates normally on the equatorial line right. So, that means; the declination angle will be 0. Because it is the angle of the sunray with the equatorial plane and if it is normally radiating on that plane, then the angle will be 0. So, delta will be 0 at the equinoxes right for both vernal and autumnal equinoxes.

Now, on the other hand, on the summer solstice; again I should remind you that whenever we call about summer, we call we talk about the northern hemisphere summer ok, So, this is so, later in the course, I will not repeat this not the hemisphere, So, for the first time, let me talk few times So, that you get the sense northern hemisphere summer ok. Now for summer solstice the sun radiates normally on the Tropic of Cancer, right; Tropic of Cancer, which lies at 23.5 again approximately north.

The latitude of the Tropic of Cancer is 23 and half degrees north ok. So, what do you expect the declination angle? What would it be on this summer solstice? That would be plus 23.5 right. So, this is the declination angle will be 23.5 degrees and the convention is north we call positive. So, that is how this is positive 23.5 degrees ok.

And in case of winter solstice we have the sun is radiating in the southern hemisphere and that is on the Tropic of Capricorn ok. So, that means delta will be negative of 23 and half degrees. Because if we call north positive, South will be negative ok.

So that is how the declination angle will change throughout the year ok. So, this we get just from the intuitive picture that we obtained from the definition of declination angle and the earth revolution around the sun ok. So, one major thing I want you to note that declination angle does not depend on the observer position, does not depend on the observer position.

This is a critical piece of information because, from now onwards, we are going to use lot many angles and it is somewhat confusing sometimes that which angle depends on what. Some angle depends on the apparent movement of the sun and some angle depends on the observer position ok.

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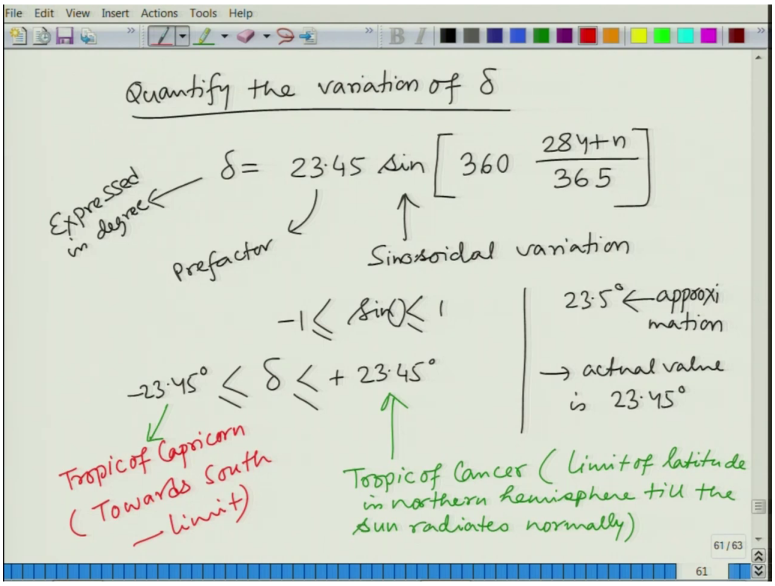

So now, if we want to quantify, the variation of declination angle ok. So this this is a fixed thing right. We do not have to; I mean, it is not dependent on observer position or the weather or anything else. It just depends on the earth revolution around the sun and which is standard thing.

So we can actually find out this and we can write a an exact equation for this case. So, declination angle is expressed as let me first write and then I will explain each term ok. So, this is the this is how declination angle changes.

So, you can see that it has a variable portion which is sinusoidal variation and this is the prefactor and of course, this whole thing is expressed in degrees in in degree. If you express it in radian the expression will change ok. And so, you have a prefactor and you have a sinusoidally variating part. Now we can say that this sin function, it can either sin of whatever it will be between plus and minus 1 right.

So you can see directly that delta will be between plus 23.45 degrees and minus 23.45 degrees ok. And I should use equality as well, because sine can be minus 1 and 1 as well. And here also the declination angle can be positive 23.45 degrees or negative 23.45 degrees ok. This we can see directly from the expression.

Now what does it mean? So, first of all, the connection that we were so far talking about 23 and half degrees. So, that is the approximation right or simplification. So, the actual value is always 23.45 degrees ok. And what this positive 23.45 means? This means the Tropic of Cancer.

This is the limit of the sun rays radiating normally if you go away from the from the equator towards the north pole. So, this is the limit of latitude in northern hemisphere till the sun radiates normally ok. And that is why we call it Tropic of Cancer.

So that is the upper limit and the opposite thing is the Tropic of Capricorn ok. And that is exactly towards south; that is the limit, the sun can radiate normally and beyond that sun cannot radiate normally ok. So that is the; that is the variation or the limits of the declination angle. Now in the expression we have.

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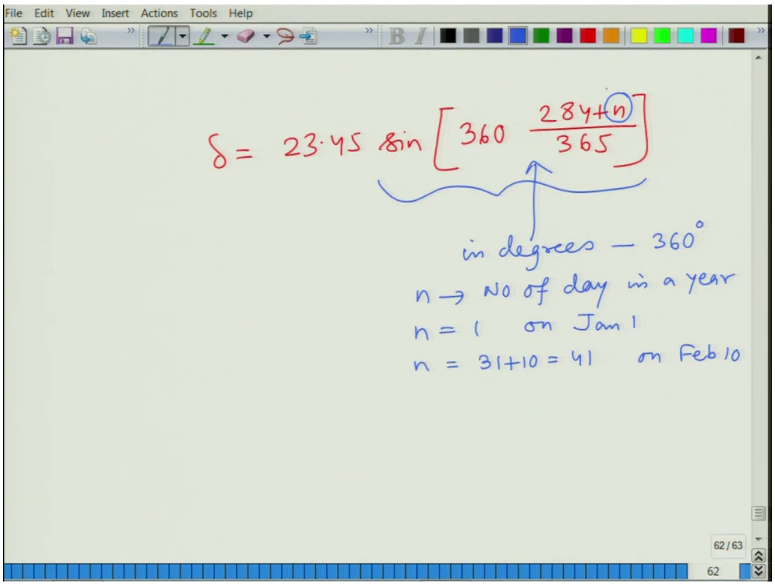


Let me rewrite this expression again. So, that we can talk about the other portions ok. So, we have looked at the limit now if we look at this sinusoidally variable portion. So, again, whatever is within the parenthesis, again it is in degrees. You can see this from the quantity 360. That is the limit of a revolution right 360 degrees ok. And what is the other part? This n again is the number of day in a year. This we have seen earlier right, n we have seen.

Now so, again, just to repeat n equal to 1 on January 1 ok. And if you are n equal to 31 plus 10 41, that is on February 10 and so on. So, for 365 days, we have 365 values of n. And depending on which day you are trying to calculate the declination angle, you will put that particular value here for n ok. And that is how you get this variability.

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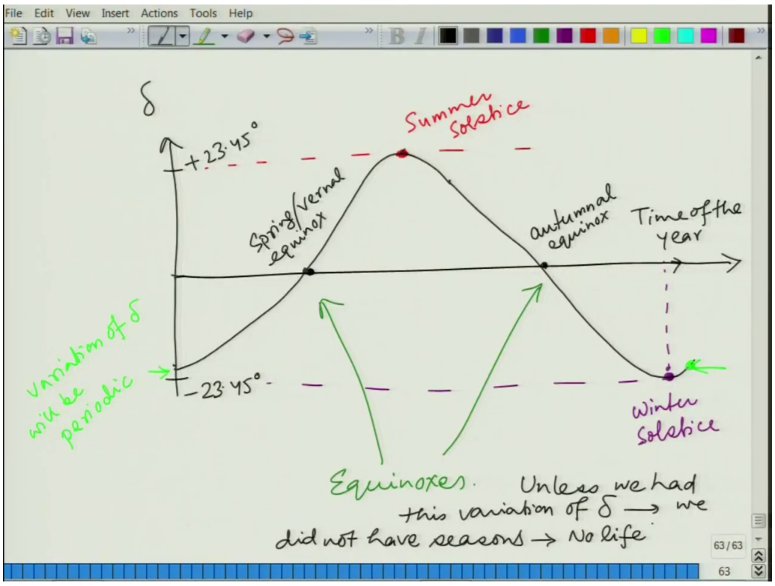

Now if we look at the variability of delta what we get? Let us try to plot it ok. So, let us say that in this axis we are plotting delta and in this axis we are floating the time of the year time of the year ok. So, first of all, we will have we know that it will be bounded by two limits; one is positive 23.45 degrees and the other one is negative 23.45 degrees. So, these two boundaries will limit the variation of declination angle ok.

And we will have two 0 points for this plot because we have two equinoxes and equinoxes mean the delta will be 0, So, these are two equinoxes. Now, delta will be maximum that is positive 23.45 degrees in case of summer solstice right. So, let us say we will have here the summer solstice ok. And winter solstice will be in December, So, let us say we have December here 21st December and then our declination angle will be the minimum ok.

So this is winter solstice declination angle will be negative 23.45 and let me increase this axis a little bit ok. So, again and for any other yearly variations, the variation of declination angle will also be periodic where whenever it starts from it has to come back again at the end of the year ok.

So, we can draw this variation of the declination angle. So, here what we see, here what we see that this point and this point has to have the same value ok. So, variation of delta will be periodic ok. It has to come back to the same point at the end of the year.

And we have the sinusoidal variation that we can see and so, if this is summer solstice, this will be between summer and winter. We have autumnal solstice sorry equinox, and on the other direction between the winter and the summer, we have the spring or which is sometimes called vernal, just the adjective form for spring equinox ok.

So, this is very interesting the declination, which actually is the major factor which tells us about the weather and this whole declination variation, is coming due to the fact that the axis of the rotation of the earth is inclined by a certain angle to the orbital plane of revolution ok.

Nothing else, it does not depend where the observer is, where you are standing and looking at the sun, it does not depend on that. It just depends on which day of the year you are talking about ok.

And unless this is, unless we had this variation of delta, we did not have seasons and probably we could not have life on the face of earth. So, no life would have been possible ok. So, this is the very important variation that we obtained which is behind the life on earth ok. Now let me insert few pages ok. Now, we will talk about the next topic, which will be the calculation of time.

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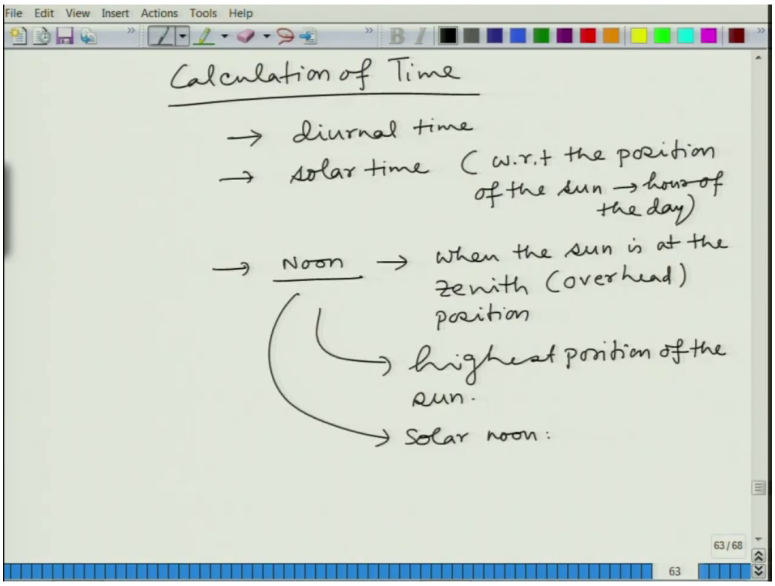

So, we have talked about the variation of declination angle which changes with thus day of the year ok. Now in a day, how the time varies? Ok. That is what we are going to look at now ok.

So before so, now I have this watch on my hand right and you also have it. You have in your computer screen, you have the timer, everywhere we have time. But before that, when all these electronic things were not there, people also followed the time of day or the diagonal time. How did people do that? They looked at the sun right. So, they were familiar with solar time. So, with respect to the position of the sun you can find what hour of the day ok.

So that is what people did. And what where the fixed point for those solar time? First one was the most important one is the noon. How people find when is noon? Noon is defined when the sun is sun is at the zenith position or overhead, zenith or overhead position ok. So, I mean for a particular day you will see that sun starts from the horizon in the east and goes up in the sky right and then goes down again in the towards the horizon. That is how sun moves apparently.

So the highest position of the sun in the sky for a particular day defines the noon. So, basically this is the highest position of the sun. That is how noon is defined. And again, if you talk about it, we should specify we should specify it to be solar noon. That is one fixed point.

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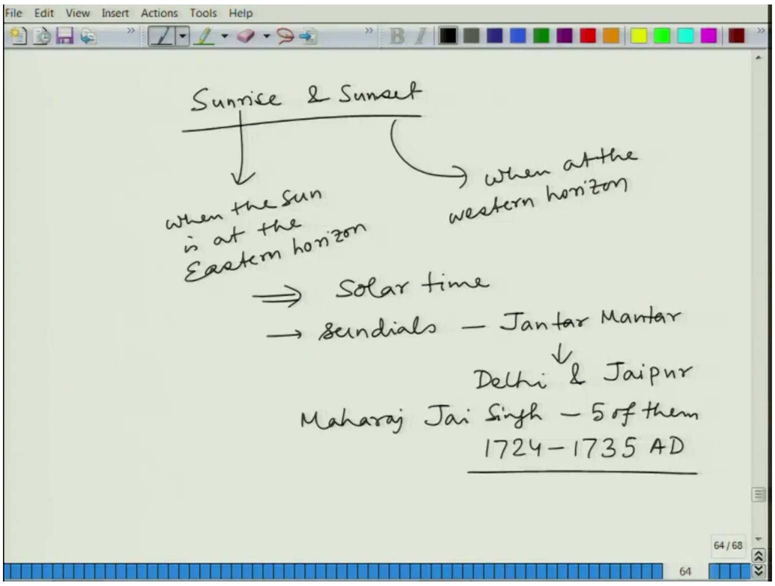
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Sunrise & Sunset
when the Sun is at the Eastern horizon
when at the western horizon
⟹ Solar time
→ Sundials — Jantar Mantar
Delhi & Jaipur
Maharaj Jai Singh — 5 of them
1724–1735 AD
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The other fixed point is the sunrise and sunset; the set of fixed point, the sun set ok. How do you define that? Sunrise is when the sun is at the eastern horizon right eastern horizon and sunset; what do we say? When it is when at the western horizon, right. That is how we define. You do not need a watch or anything. You just see the sun, you can say this is the sunrise point, this is the sunset point and this is the noon point.

This you can define and that is actually called solar time ok. And this people have understood very meticulously particular in India; you if you have visited this sundials ok. Very elaborate sundials are there in the Jantar Mantar. I guess lot of you have visited it. If not, you should, because then you can appreciate before there was watch how people could very accurately could find out time. And Jantar Mantar, you can find it in Delhi and Jaipur ok.

And actually there are total 5 of them ok. So, this Maharaj Jai Singh, he actually build these things So, total 5 of them and only 2 are alive today, other 3 are destroyed presently and they were made like 300 years ago within this time period ok.

So, that is very interesting and I think as kid you all have placed some stick on the ground and you have looked at how shadow moves for that stick right and that also gives you a very preliminary form of a sundial from which you can find out the time of a day.

And if you have not done that as a kid; in this course, at least you should go back and do that very basic experiment ok. And you will enjoy it, I can say ok. Now the critical portion is ok. We have the solar time, which is we do not need a watch for that, but ultimately, the world runs on certain times right your watch and my watch has to give the same time. Then only we can fix a meeting, we can the trains can run right.

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## Standard time — Solar time varies from place to place

→ we need some standard to fix this variability

→ Connection

$$\text{Solar time} = \text{standard time} \pm 4\,(L_{st} - L_{loc}) + E$$

- Solar time ↑ Sundial shows
- standard time ↑ what your watch shows
  - ↳ for uniformity we fix a location in a time-zone for which the solar time serves as the standard time

We have to have some basis for standard time ok. So, next thing we need to know is standard time. So, we cannot carry the sundials and the sundials will give you different time at different places right. Because sun rises at different time at different places. So, we need some standardization, that is what we need the standard time. So, solar time varies from place to place right.

So, we need some standard to fix this variability right and that is what we do call the standard time and that is what your watch is showing you right now. So now what would be the connection?

We need to connect these two dots right the standard time which your watch is showing and the solar time and that connection is given through this equation. So, solar time is standard time plus minus 4 L st minus L L oc plus E ok. That is the equation that connects solar time and standard time and what are all these terms we will come one by one ok.

So solar time is what your sundial is giving what sundial shows right. And standard time is actually what your watch shows ok. And how are they connected with these other things? But your watch So, if you are in Bombay, your watch and my watch I am at Kanpur, both of them, if they are correct, are giving the same value, how is that possible? Ok.

So that is why we for uniformity we fix a location for which or we fix the location in a time zone ok. We call it time zone for the area which will have to follow the same time ok. So, for us, the whole India is the time zone and we call it Indian Standard Time or IST ok. So, for this time zone we have fix location the solar time for which serves as the standard time.

So, your watch does not know whether sun is up or not, whatever it whenever you fix it, it follows the same algorithm and runs at a constant speed. And that is how whenever you fix it to the standard time, then it will follow it will give you the standard time always ok.

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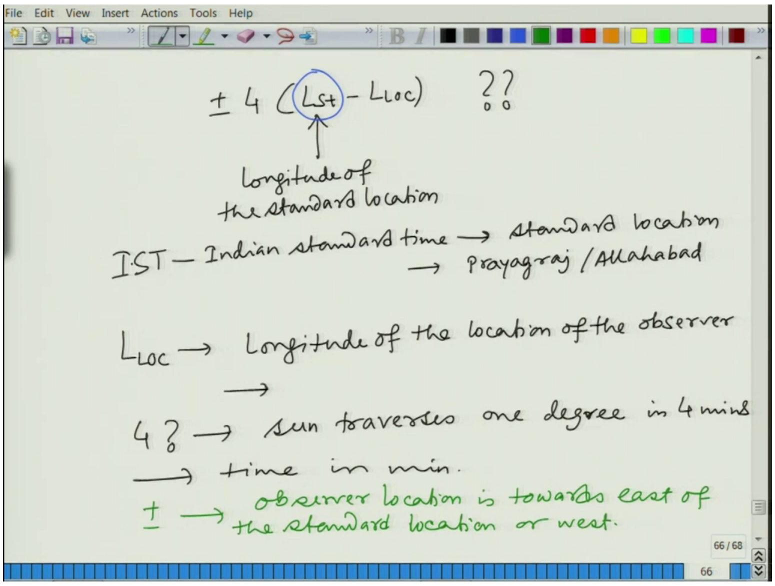
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± 4 (Lst - Lloc) ??
Longitude of the standard location
IST — Indian standard time → standard location
→ Prayagraj / Allahabad
Lloc → Longitude of the location of the observer
→
4 ? → sun traverses one degree in 4 mins
→ time in min.
± → observer location is towards east of the standard location or west.
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Now what is this plus minus 4 L st minus L LOC part ok. What is this? First of all, I would say that this L st stands for the latitude sorry not latitude, longitude of the standard location ok. So, for India for Indian standard time Indian we have fixed this location to the standard location to be the Prayagraj or Allahabad ok. This we fix, because it lies almost in between the east and west boundaries of the country; that is why we fixed our standard time location to be at Allahabad ok.

And all the watches in India they will follow the solar time of this location. That is a convenient agreement that we did between ourselves ok. Now this L st L st is the longitude of this particular standard location which is Allahabad for our case. And what is L LOC? This is the longitude of the location of the observer ok. So, if you are at Guwahati, that would be your the longitude of Guwahati will be your L LOC ok.

And how come this factor 4 is coming? 4 is actually coming from the fact that the sun traverses 1 degree in 4 minutes ok. Because it traverses 360 degree in 24 hours. So, if you compute that you will get it traverses 1 degree in 4 minutes ok. That is why that factor 4 is coming and you can say that all this time that we are writing time in minutes ok.

So solar time, So, if we go back to the equation here, in this equation sorry in this equation the solar time and standard time; the difference will be coming in minutes that is why we are using this factor 4. And there is one more thing here yeah. This plus minus this plus minus is coming weather the observer location is towards east of the standard location or west ok.

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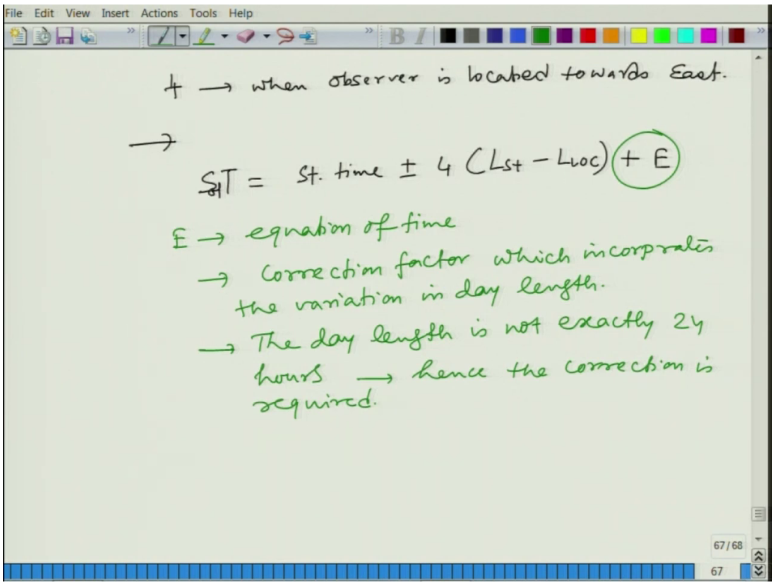


So, that is the so, the convention or rather the fact is positive stands for when observer is located towards east ok. This you can understand very easily like the sun rises in the east right. So, if you think of Patna, which is towards east of Allahabad right.

So, sun rises there first ok. So, the time will be the solar time will be higher in Patna compared to Allahabad. But you are adjusting your clock so, that it shows the same time ok. So, that is why the sin convention is coming ok.

Now another factor, so, let me write this equation once again. So, solar time equal to or rather solar time equal to standard time plus minus 4 L st minus L LOC plus E ok. Now we have not talk about this E. E is called equation of time, which is nothing but a correction factor that we need to add to this equation.

So, this is a correction factor which incorporates the variation in day length ok. Because our days or the time it takes to rotate the earth around its axis is not exactly 24 hours ok. So the day length is not exactly 24 hours. Hence, the correction is required ok. And the correction is done through the form of this equation of time ok.

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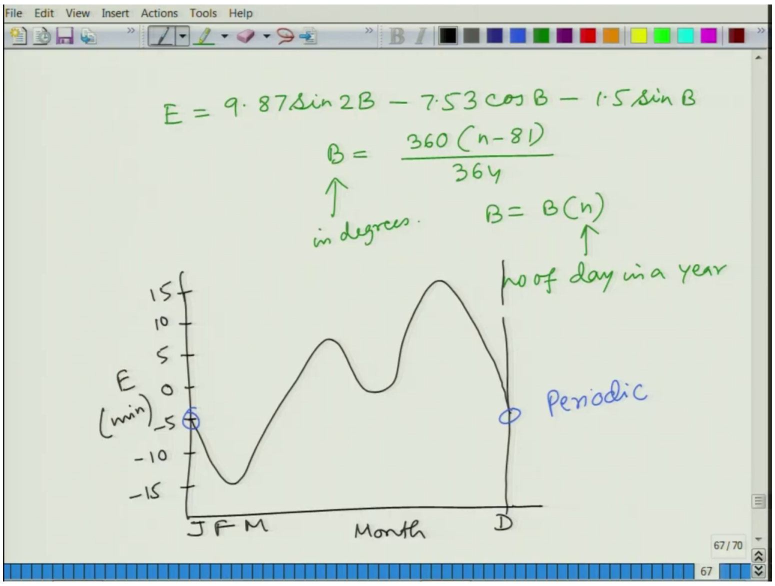

So now what is that correction? So, equation of time is 9.87 sin of 2 B minus 7.53 cos of B minus 1.5 sin B ok. And this is in, so, this B this is computed through this equation ok. So again this B in degrees and B is a function of n ok. n is again the number of day in a year. So, January 1 is n equal to 1 ok.

So, if we look at the variation of it ok. Let us say this equation E in minute and this is month ok. And so, let me write few of these, 0, 5, 10, 15 and So, on ok, So, it varies somewhat like this ok. And, again, like any other yearly variation, it has to be periodic, it has to come back from where it started ok. They have to be periodic.

And yeah, So, this is starting from January, February, March and So, on till December ok. So, you can see that it goes approximately about plus minus 15 minutes you have to adjust for this day length correction ok.

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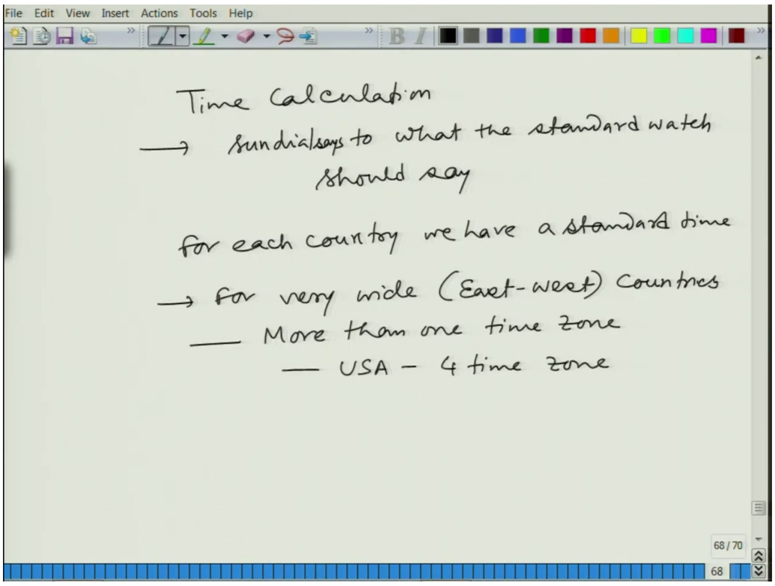

So, overall we have obtained the time calculation we have seen which connects between what the sun says or the sundial says to what the standard watch should say. So, what sundial says to what the standard what should say and it incorporates where exactly you are depending on the standard time location east or west and also incorporates the day length variation which is accounted for by the equation of time ok.

So one point I should tell you that for each country we have a standard time. Because a whole country should follow the same time right. But the country is very spread out in east west direction ok, then it will be very difficult if you use the same time. Then in some part the sun will rise at 10 o'clock in the morning and in some part it will rise at 4 in the morning. So, it will be very difficult if the countries spread out in east west direction ok.

So and for any office or anything running smoothly, you have to fix the time. So, if the office time starts at 9 and if it is middle of the night or sun is not out yet, you cannot go to the office right. So, that is why, for very wide in the east west, north south, it does not matter. If it is wide in the east west direction, wide countries often they have more than one time zone. Like in US, you have 4 time zones, the time in New York is not same at as the time at Chicago, it varies ok.

So, that is how they managed this problem. In India also, we are thinking of introducing more time zones. So, that the sun, the sunny hours can be utilized much more effectively. Like in Guwahati and Bombay; the sun sets at much later time. In Bombay, the sunsets later than Guwahati right. So, in Guwahati, you should start your office hour little early and end your office hour little early as well, compared to Bombay ok.

Then what we can gain is that we do not need to use that many electric lights ok. If you shift your office hours accordingly and that is why people are thinking of introducing more time zones to save electricity and it will be very and we are in this solar energy course right. So, we can understand why the why it is very much needed to save electricity and go renewable ok.

So, here I stop for today and in the next class we are going to talk about the role of atmosphere in solar radiation ok.

Thank you so much for your attention.