Renewable Energy Engineering: Solar, Wind and Biomass Energy Systems
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Lecture - 1
Solar Energy: An Overview of Thermal Applications

Hi everyone. Good morning. So, today, we are going to start the course. Today, we are here for lecture 1 of Renewable energy engineering: solar, wind and biomass energy systems. Among these three major renewable energy systems, I am going to handle solar and wind energy systems and my colleague professor Gowd would be handling biomass energy systems.

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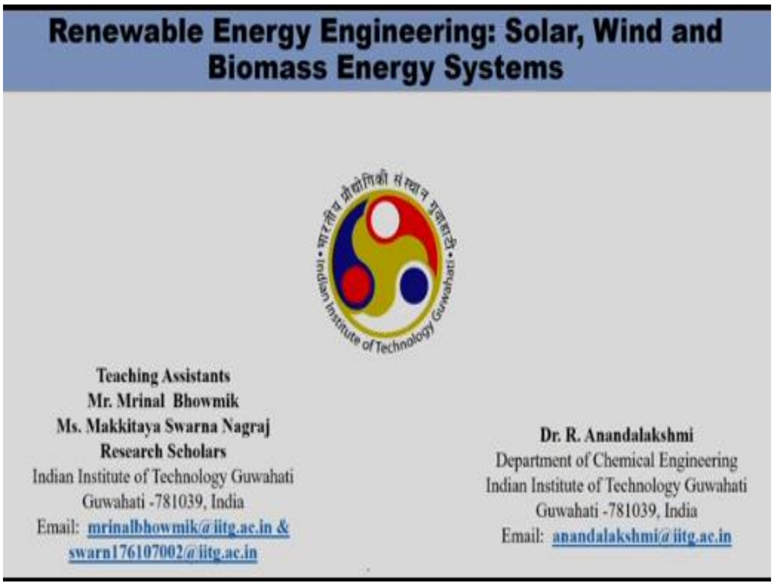

Mr Mrinal and Miss Swarna both are going to be teaching assistants for solar and wind energy systems and their mail id is given and if you have any course related queries, you can write to me and you can take help from teaching assistants as well.

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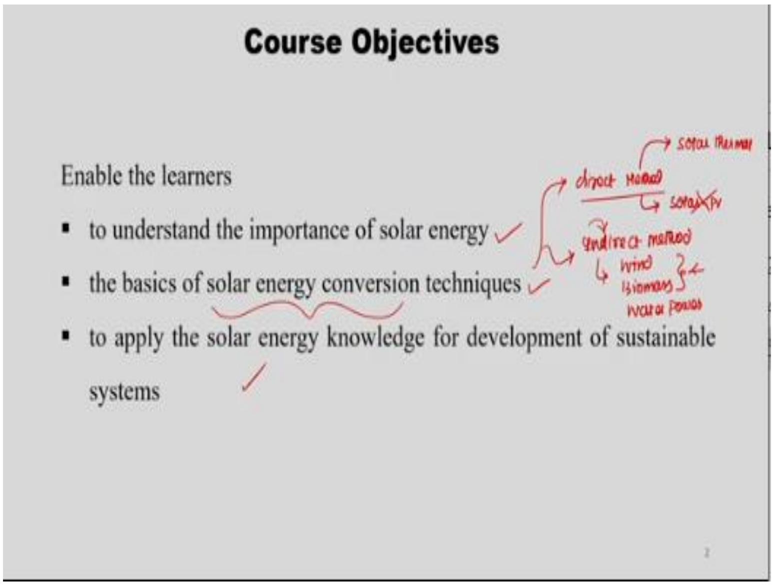

As far as course objectives are concerned. This course would enable the learner to understand the importance of solar energy and the basics of solar energy conversion techniques. The moment we say about solar energy conversion techniques, there are two types. One is direct method; the other one is indirect method. In the direct method, we will talk about solar thermal. There is another conversion solar PV that we are not going to discuss about in this course.

And indirect method wind, biomass, water power etc. would come but we are restricting ourselves to wind and biomass energy system. So, directly it can be converted or the temperature difference created by solar energy can help us in this indirect method of conversion. Also, this course would enable the learner to apply the solar energy knowledge whatever you gain out of this course may be useful for the development of sustainable systems in future.

So, in short it would help you to understand the importance of solar energy and solar energy conversion techniques. It will also be useful for the development of any sustainable system in future.

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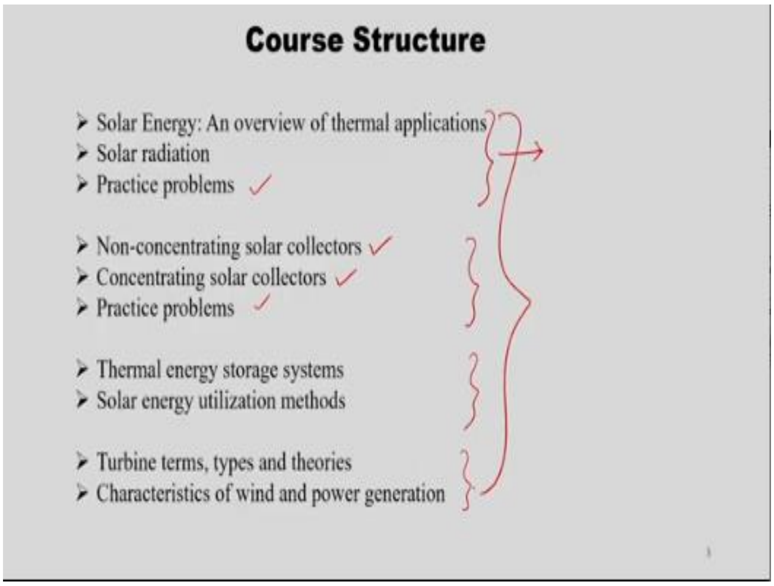

The core structure goes like this. The solar wind would be covered in 4 modules. The first week, first module have three lectures. One is on solar energy overview of thermal applications; second lecture would be on solar radiation; third lecture will be on practice problems on how to calculate solar radiation parameters.

The second module of second week includes non-concentrating solar collectors, concentrating solar connectors and the practice problems on how to design non-concentrating or concentrating solar collectors. Third module of third week includes thermal energy storage systems, solar energy utilization methods. Fourth week of module 4 includes turbine terms, types and theories of wind energy and characteristics of wind and power generation.

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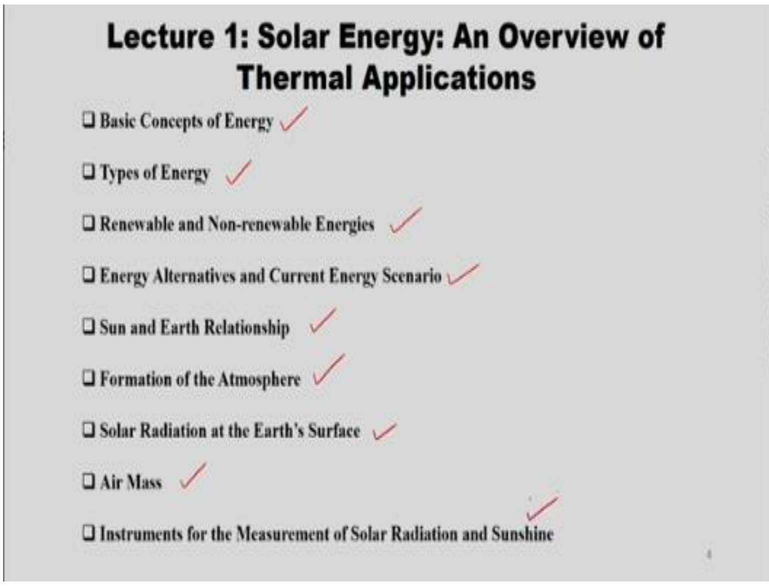

In today's lecture of solar energy and overview of thermal applications, we would be discussing basic concepts of energy, types of energy, renewable and non-renewable energies, energy alternatives and current energy scenario, sun and earth relationship, formation of the atmosphere, solar radiation at the earth's surface, air mass, instruments for the measurement of solar radiation and sunshine.

Along with, we will review some of the solar thermal applications. The first topic would be on basic concepts of energy. So, if you are already working in energy engineering or chemical engineering or mechanical engineering so, you are comfortable with these terminologies and the units of energy. However, since this course is common to all students who are willing to learn renewable energy engineering as well.

So, we are going to review about the terms related to energy and their units. So, energy is defined as ability to do work. So, in ancient times, the primitive man required energy in terms of food. So, after the discovery of fire, he learned how to cook and eat. So, for that he required wood and biomass other than fire. Then after that he started cultivation and then agriculture. So, there he required animals and missionaries to help him for the agricultural purpose.

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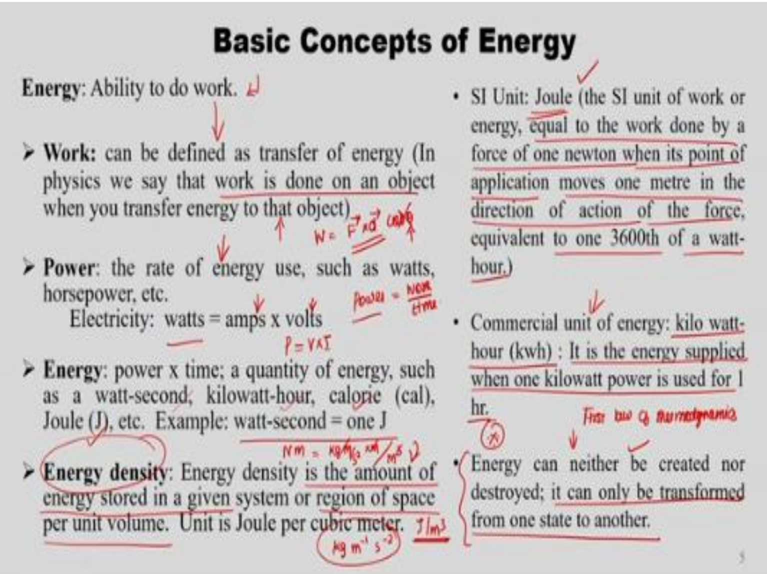

That is the way the energy requirement started increasing day by day. And in ancient times so, the whole energy needs of mankind was served from solar energy only. Then after the invention of internal combustion engines then we started using non-renewable energy sources as well. Here energy is nothing but ability to do work. So, then we will define work. Work can be defined as transfer of energy.

In physics, we say that the work is done on object when you transfer energy to that object. It is not only when you transfer the energy to that object. So, because of transfer the object should move. So, work is defined as force into displacement and multiplied with cos theta. So, this theta is nothing but the angle between F and d. So, if both are in same direction then this would be 0. So, this is 1.

So, work is defined as F into d that is force applied and the displacement. And then power; the rate of energy use, power is defined as work upon time. So, if you are working in PV, solar PV then power is defined as power is voltage into current. So, voltage unit is volts; current unit is amperes; power is in watt.

So, if you are working in solar thermal, then energy is nothing but power into time a quantity of energy such as a watt second or kilowatt hour or calories or joules etc can be used as a unit of energy. One watt second is nothing but 1 joule. Then here in this course we are also going to discuss about thermal energy storage system. So, there this particular term would be used frequently that is nothing but energy density.

Energy density is the amount of energy stored in a given system or region of space per unit volume. So, the unit is joule per meter cube. So, if you are working on basic SI units, joule is defined as work done. Work done can be defined as Newton meter that is force into distance. Newton is nothing but kg meter per second square into meter. So, energy density is nothing but an amount of energy stored in a given system or region of space upon volume.

Volume is in meter cube. So, then your unit would be kg meter power minus 1 second power minus 2 if you are working in basic SI units. So, this is the way the work power energy and energy density can be related. So, SA unit of joule can be defined as the work or energy. Joules unit of work or energy which is equivalent to work done by a force of one Newton when its point of application moves 1 meter in the direction of action of the force.

That is what here we said force into distance. It is also equivalent to one 3600th of watt hour. The commercial unit of energy may be, you might have seen in electricity measurement at your home. So, that is in kilowatt hour. So, it is the energy supplied when one kilowatt power is used for 1 hour and this is the basic law of conservation of energy that is energy can neither be created nor be destroyed it can only be transformed from one state to another state.

So, this is the basis for first law of thermodynamics then we will review about laws of thermodynamics with which we need to define our design the energy systems.

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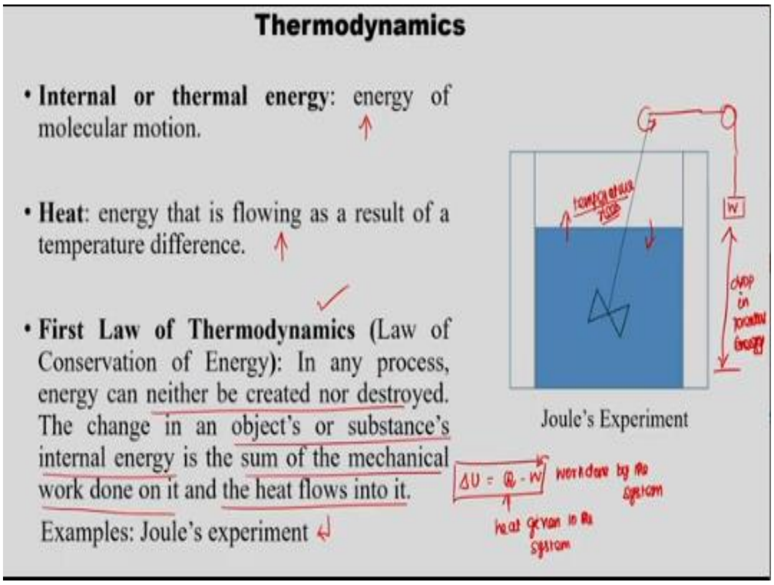

But I am here not going into deep just to make you aware of these concepts and to remind you so, whatever you learnt on thermodynamics are basic science at school level. Internal energy is nothing but a energy of molecular motion. Heat is nothing but the energy which is flowing as a result of temperature difference and first law of thermodynamics it is nothing but a conservation of energy.

In any process, energy can either be created or not be destroyed and the change in objects or substance's internal energy which is nothing but del u is the sum of mechanical work done on it and the heat flows into it. So, del u is nothing but Q minus W. So, this is heat given to the system. So, this is we take it as a positive quantity. So, this is work done by the system. So, that is negative a sign we will give for work.

So, del u is nothing but Q minus W. First time the researcher Joule. So, he did a experiment and came up with the relation between work and heat. So, he came up with certain kind of arrangement where insulated vessel is there. So, there he kept 1 stirrer and he connected this it into a pulley arrangement. And connected with some weight. So, when the weight is going down.

So, this paddle will arrangement which is connected with the pulley and the thread. So, it rotates this stirrer when it rotates automatically the fluid inside the vessel gets heated and temperature rises . So, this drop in weight, we calculate as a drop in potential energy. So, that helps in work done on the system. Through the stirring and due to which the temperature rises. So, that is converted into heat energy.

So, this is the relation he proposed first before that heat was identified as a calorific fluid. So, the first law of thermodynamics came up with the relation between work and heat. And also it said that the change in object substance internal energy is the sum of the mechanical work done by or on the system and heat flows into or out of the system.

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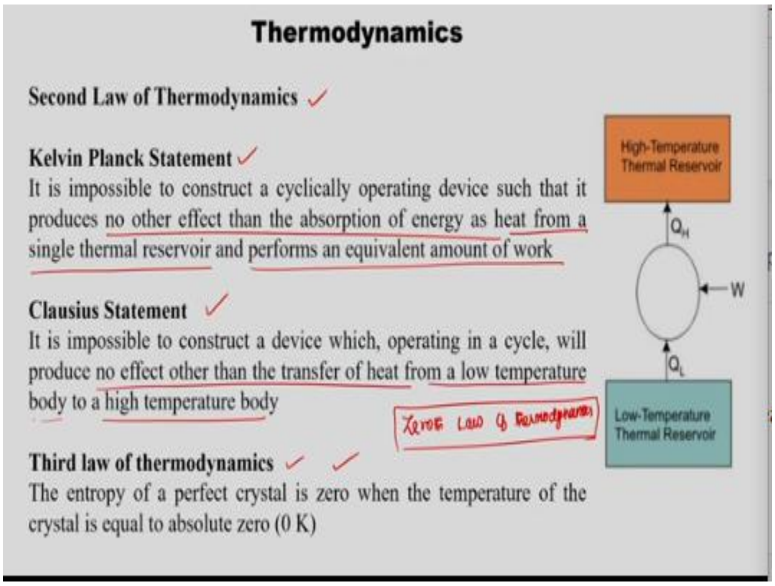

And then second law of thermodynamics. So, we have here her two statements. The one is the Kelvin Planck statement. So, it says that no other effect then the absorption of energy as heat from a single thermal reservoir and performs an equivalent amount of work. So, any heat cannot be converted a 100% into work. So, that is the basic concept of Kelvin Planck statement and then Clausius statement.

So, here this statement says that no effect other than transfer of heat from a low temperature body to a high temperature body. We cannot extract heat from low temperature body to high temperature body and this is the third law of thermodynamics. The entropy of a perfect crystal is 0 when the temperature of the crystal is equal to absolute 0. That is nothing but 0 Kelvin.

So, what third law says is, it precisely tells you that you cannot get a absolute 0 in a finite number of steps. So, that is the concept of third law of thermodynamics. So, at absolute 0 there cannot be any environmental parameter. You can manipulate to change the entropy if t is 0 then s is 0 no matter what. So, that is the third law of thermodynamics. Apart from first and second and third law of thermodynamics, there is something called Zeroth law of thermodynamics.

So, it says that objects in contact with one another will share the heat energy until they reach thermal equilibrium. So, that is nothing but Zeroth law of thermodynamics. It also states that if two objects are in thermal equilibrium with the third one then they are all in thermal equilibrium. So, that is nothing but Zeroth law of thermodynamics. So, any heat transfer system or energy conversion devices will work based on these laws of thermodynamics.

That is what here we are reminding us one more time so, that we will be careful in doing calculations.

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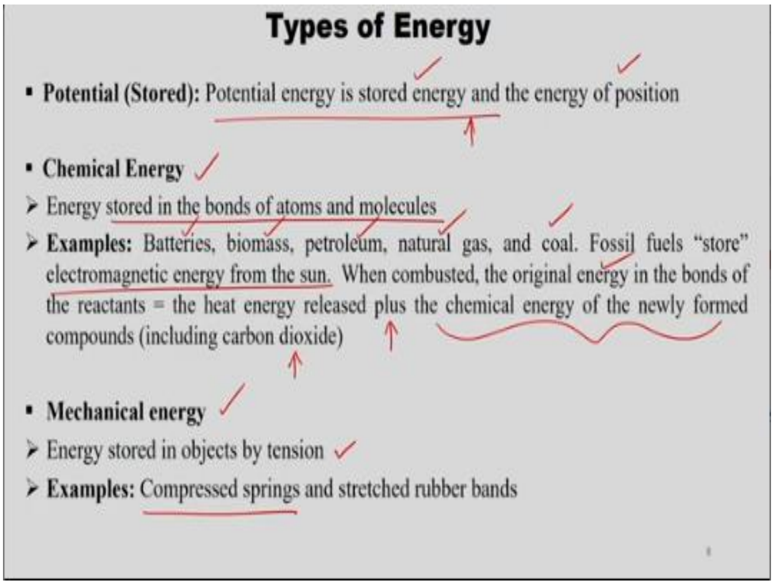

And then types of energy the major types of energy are potential energy and then the kinetic energy. The potential energy is nothing but stored energy or energy of position and kinetic energy is nothing but motion of waves, electrons, atoms, molecules, substance and objects under potential energy there are various kinds: chemical energy, mechanical energy and then nuclear energy gravitational energy.

So, what is chemical energy under potential energy? Energy stored in bonds of atoms and molecules. So, examples are batteries where you can store the electrical energy and biomass where you can store the energy and then petroleum, natural gas and coal. And fossil fuels store electromagnetic energy from the sun and when combusted the original energy in the bonds of the reactants. That is what we told stored energy.

So, when you compost these fossil fuels, what happens is that the energy which is stored in the bonds of the reactants will be released. So, that is equivalent to the heat released plus chemical energy of the newly formed compounds. So, if you burn the coal, you will also get carbon dioxide as a by-product trade. So, this energy also equivalent to the stored energy and then mechanical energy, energy stored in objects by tension.

The example is compressed spring. When you apply the force, you compress. When the force is released, energy is also released. So, energy stored in objects by tension is nothing but mechanical potential energy.

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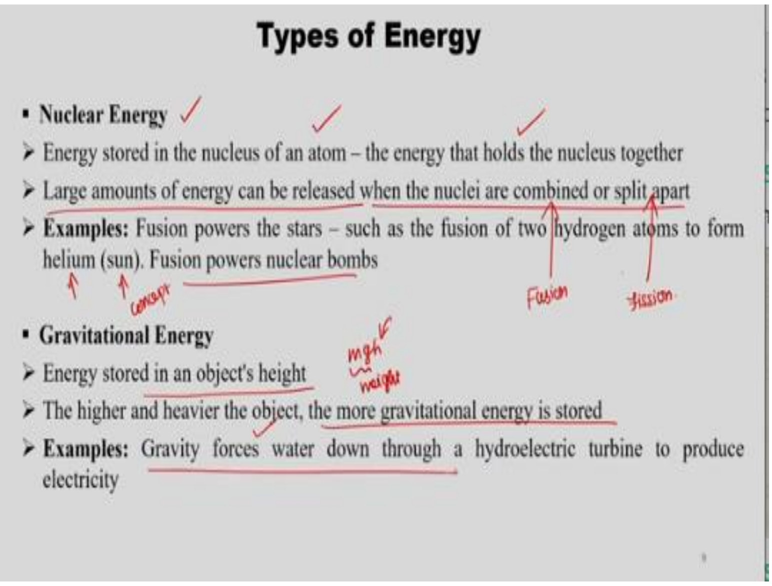

Next one is nuclear energy. So, this is nothing but energy stored in the nucleus of atom. So, this energy is nothing but the energy that holds the nucleus together. The large amounts of energy can be released when the nuclei are combined or split apart. So, when you combine, this is called fusion. So, when you split, it is called fission. Fusion powers the star such as fusion of two hydrogen atoms makes a helium.

So, this is the concept of sun that we will discuss anyway. And fusion powers nuclear bombs as well. So, these two are examples for nuclear energy under potential energy and then gravitational energy. So, energy stored in an object's height. So, this we call it as a mgh. So, where mg is nothing but weight of the object. So, h is nothing but the height. So, the higher and heavier the object, heavier is, weight is high or height is higher than you would get more gravitational energy stored.

So, the gravity forces the water down through a hydroelectric turbine to produce electricity is nothing but an example for this gravitational energy.

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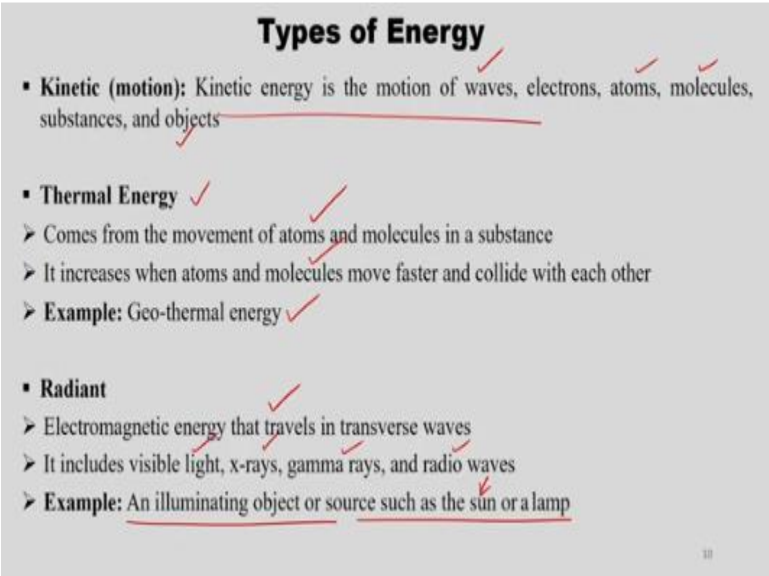

So, next we are going to discuss about the kinetic energy. So, under this, thermal energy, radiant energy, electrical energy and motion energy comes. Thermal energy comes from the movement of atoms and molecules in substance. So, it increases when atoms and molecules move faster and collide with each other. The example is geo-thermal energy. So, what we get from the earth core and then the second major kinetic energy is radiant energy.

So, that is due to electromagnetic energy that travels in the transverse waves. It includes visible light x-rays, gamma rays and radio waves. Example is an illuminating object or source such as sun or a lamp. So, these three are examples for radiant energy. However, as we said earlier so, this sun or electromagnetic waves of the sun can also be stored in fossil fuels when you burn them then you will get them as a chemical energy as well.

So, this we have already discussed it conservation of energy. One form can be converted into another form. Then the next one is electrical energy.

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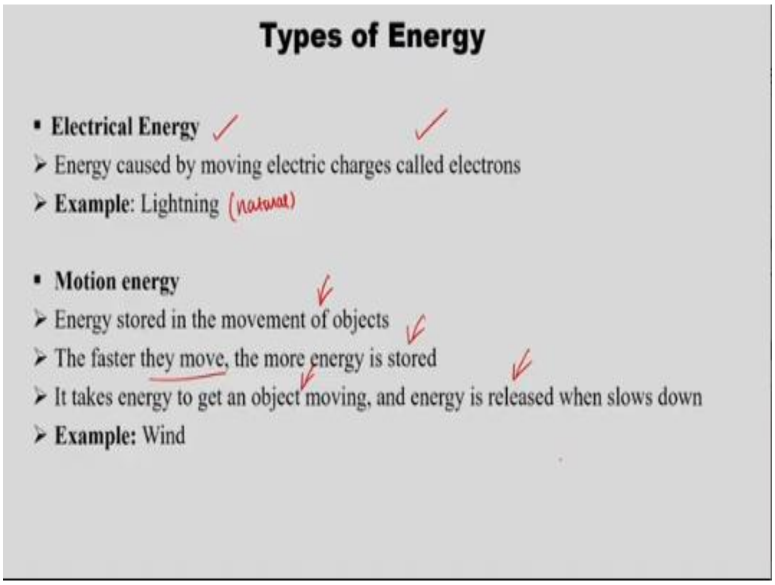

Energy caused by moving electric charges called electrons the natural electrical energy is nothing but a lightning process and then the motion energy. So, energy stored in the movement of objects the faster they move more energy is stored. So, that is the way it comes under kinetic energy. It takes energy to get an object moving and the energy is released when the object slows down. So, example is wind. We will discuss anyway in this course about that.

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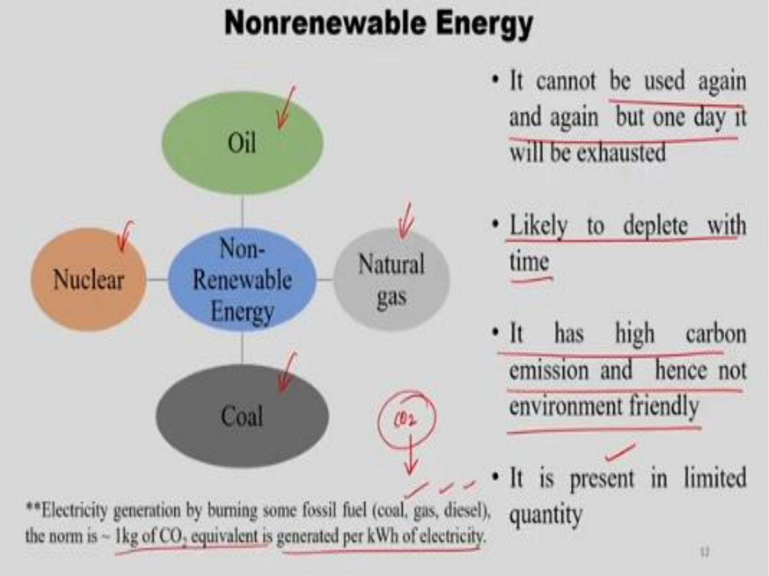

So, this is basic certain types of energy. But if we want to discuss the types of energy in terms of its usage then we will have two major category. One is non-renewable energy. Another is renewable energy. So, non-renewable energy are like what we have right now for our energy needs the oil, coal, nuclear and then natural gas. So, they cannot be used again and again but one day they will be exhausted and likely to deplete with time.

It has high carbon emission and hence not environment friendly. So, because when they burn so, they also produce CO2. So, because of which they are not environment friendly. It is present in limited quantities and in terms of environmentally safe, it is said that electricity generation by burning some fossil fuel a coal or gas or diesel. The norm is 1 kg of CO2 equivalent is generated per kilowatt hour of electricity.

So, that is what we call these non-renewable energies as a they are not a clean energy. The next one is renewable energy.

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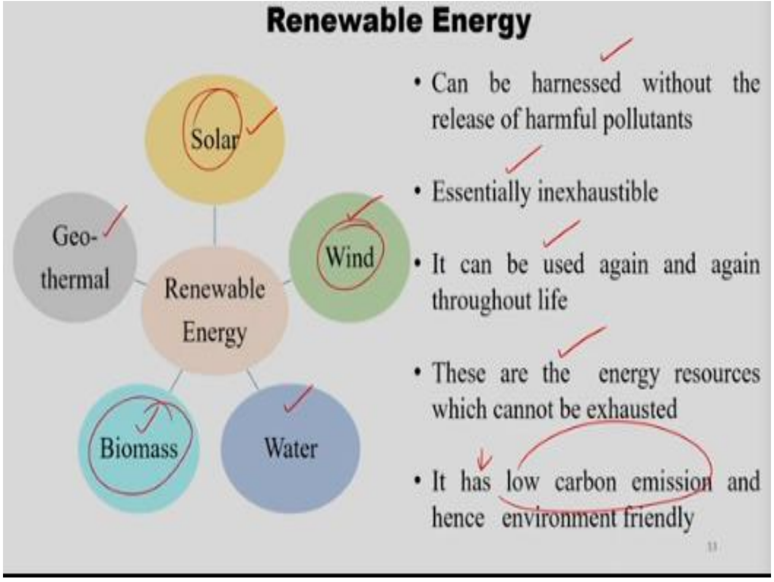

They can be harnessed without the release of harmful pollutants that is a major advantage and they are essentially in exhaustible and it can be used again and again throughout the life. They are the energy resources which cannot be exhausted. It has low carbon emission and hence environment friendly. So, they are solar, wind, water, biomass and geothermal. So, in this course we are going to discuss about solar, wind and biomass, three major renewable energy sources.

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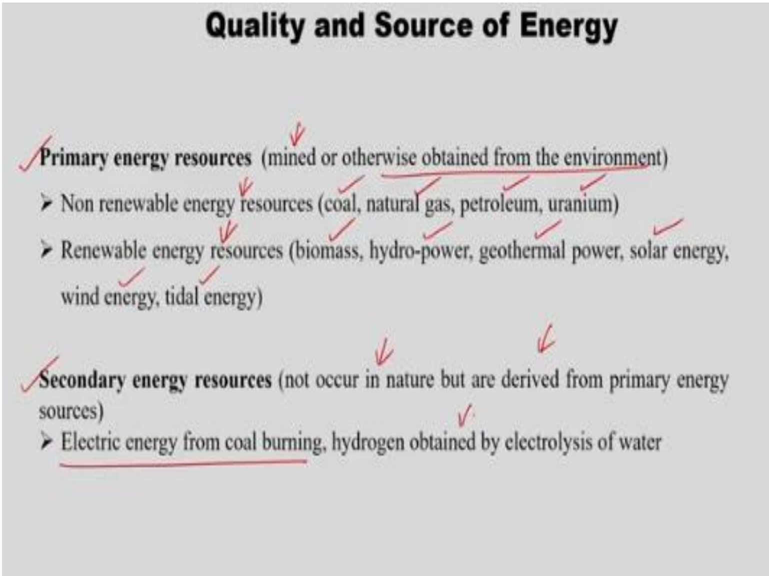

And then the quality and source of energy based on that quality we can have two primary energy sources and secondary energy sources. The primary energy sources are, they are directly mined or otherwise obtained from the environment. So, mind is coal, natural gas, petroleum and uranium. So, they are called non-renewable energy sources and if we get from the nature or environment, they are called renewable energy sources.

As we said biomass, hydropower, geothermal, solar, wind, tidal, everything comes under this category. Secondary energy resources are not occur in the nature or mind but are derived from the primary energy sources that is converted. So, electrical energy from coal burning we can convert this heat energy into electrical energy and hydrogen obtained by electrolysis of water.

So, that also comes under secondary energy resources. So, now pretty much we have discussed about the basics before going to discuss solar energy.

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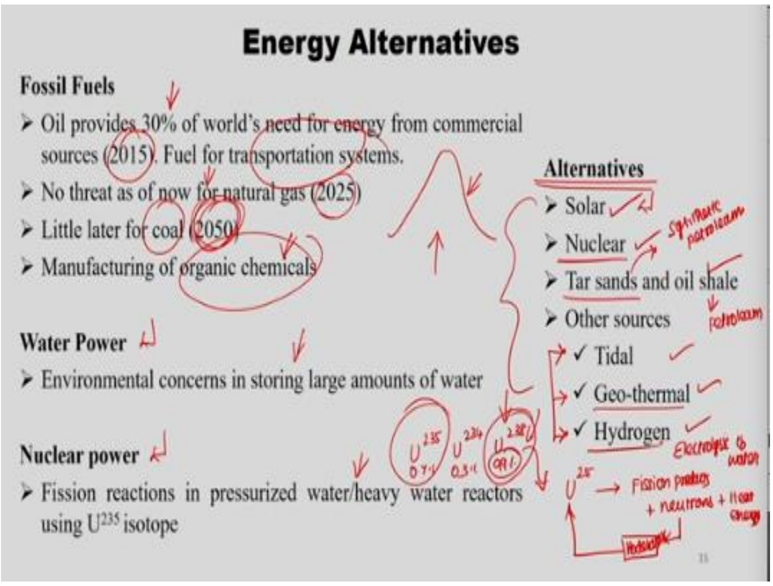

So, we have learnt what is the basic concepts of energy and then types of energy in terms of the stored energy and the energy created due to movement and then we defined them based on their availability and the source of the energy. So, now why we need to think about energy alternatives for whatever the energy available today for our energy needs. So, most of our energy needs we are depending on the fossil fuels.

In fossil fuels, oil provides 30 percentage of world's need for energy from commercial sources. So, any non-renewable energy as we said already. So, it is not inexhaustible in nature. So, due to which there would be a increase in production and there would be a peak production and there would be a declination period. So, for the oil, the model says that 2015 was the peak period after that the protection capacity or production of oil would decrease.

So, this is the major fuel for all our transportation systems in the present day and as far as natural gas is concerned, no threat as of now but the peak period would be sometime around 2025 that is 2025 and for coal it is little later probably 2050. So, because after certain time, right after 2050 so, we cannot depend solely on the fossil fuels. Because all would be in the decline mode.

And apart from energy needs these non-renewable energy sources are used for manufacturing of organic chemicals. So, in the decline mode they may not be able to be used to manufacture organic chemicals because in the declination mode probably we might be using only energy needs. So, the plants which are dependent on the non-renewable energy source for manufacturing of organic chemicals should be affected.

So, it is the right time for us to think about various energy alternatives instead of these fossil fuels. So, the two major alternatives are water power and nuclear power. In the water power, we can use it but the problem is the environmental concern in storing large amount of water. So, already in many parts of India, we are facing water scarcity. So, again that put the constraints to use water power without any worry.

So, then the next one is the nuclear power. So, here fission reactions in pressurized water or heavy water reactors, we can create nuclear power using uranium 235 isotope. So, here we have resources for uranium 235, 234 and 238 but their availability if we see this is around 0.7. So, this is around 0.3 and then 0.3%, 0.7% and this is around 99% but right now, we have the technology to use uranium 235.

But still it can cater our energy needs but if we have some alternative technology which uses or which converts uranium 238 as a fissile material. Then we might be in better position to think about nuclear power as a alternative energy source. So, after discussing or after getting to know these facts so, we can come up with certain better alternatives. So, which are solar and nuclear and tar sands and oil shale, tidal, geo-thermal and hydrogen.

So, solar is obviously the better option and we will also discuss the fact why it can be considered as a better alternative but in nuclear already we discussed like you have a uranium 235. So, that is bombarded with the neutrons and give the fission products. Fission products plus first neutrons plus energy, heat energy. So, we will use some moderator to convert this neutrons into slow neutrons and then we again bombard this isotope.

I am not getting into detail because this is not of our interest but I am telling like what further can be done. So, as we said if we develop some other technology to use the major available resources of uranium 238 or we can come up with better technology then converting this particular fertile material into some other fissile material and that can be used to extract the energy.

So, with these technologies we can think of this as a better alternative option and tar sands we can produce the synthetic petroleum. So, that we are not depend on the natural fossil fuel and oil shale also can be used to produce the petroleum and tidal energy, this comes again under water power and geo-thermal as we said, we are getting energy from the earth core and hydrogen, this can be done by electrolysis of water already we have said that electrolysis of water.

Again these two comes under water power and this comes under the energy from the earth. So, these can be the alternative energy or we need to come up with alternative technology to what are all the available technologies today. In that way, we can think of alternatives to available non-renewable energy resources today.

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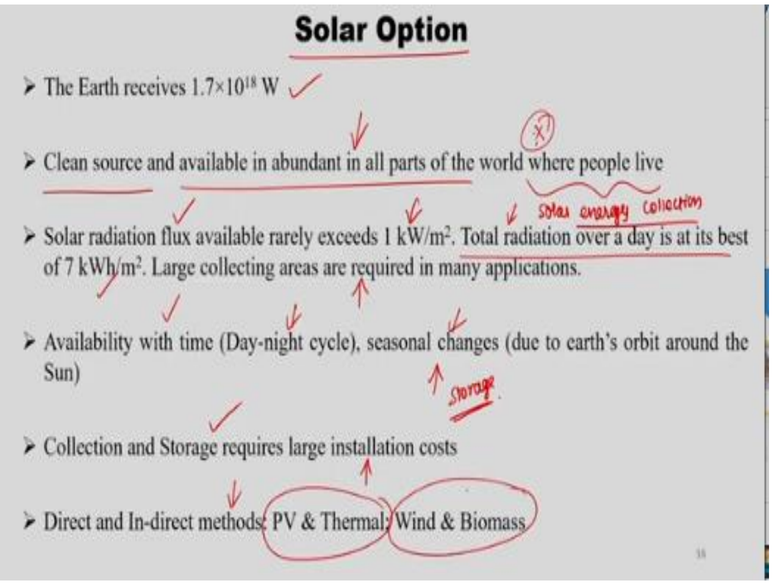

So, in that the first and better option we thought about us the solar. So, earth receives around 1.7 into 10 to the power of 18 watts of solar energy and it is a clean source and it is available in abundant in all parts of the world where people live. So, this is major advantage but disadvantage side the solar radiation flux available rarely exceeds 1 kilowatt per meter square. So, total radiation over a day is at its best of seven kilowatt hour per meter square.

So, we would be requiring large collecting areas for many thermal applications and also the another disadvantage is, its availability is depend on time. So, due to day night cycle and also there would be seasonal changes due to earth's orbit around the sun. So, because of these two reasons we would also require the storage. So, here we need to improve the solar collection, solar energy collection. So, here we need to think about storage as well.

So, these two major requirements lead to large installation cost. So, in terms of availability, it is abundant but how to collect and how to store when it is excess and that will be used when there is a scarcity is something that we need to think about and this can be used as a direct method as well as indirect method. Direct method PV & thermal and indirect method is wind & biomass.

So, here we are not going to discuss about PV, only the thermal, wind and biomass. So, current energy scenario in terms of solar energy.

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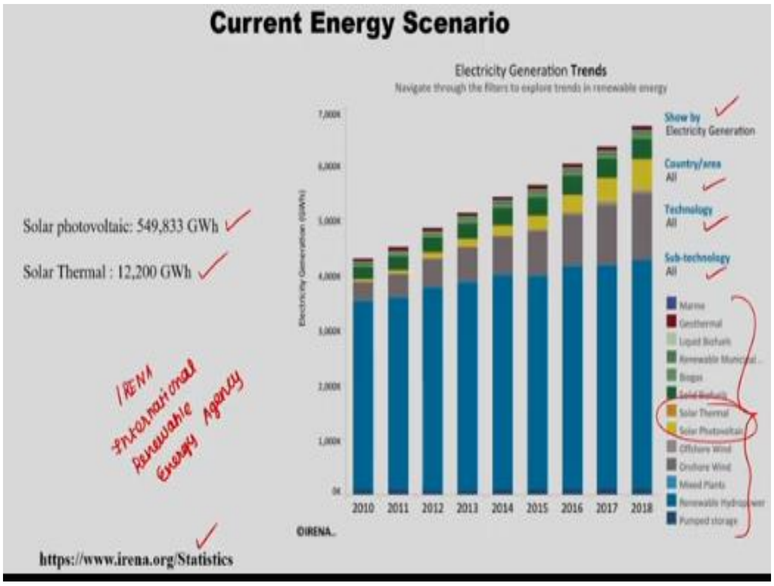

So, this is taken from arena. So, this is international renewable energy agency. You can check in the site. So, here electricity generation we have taken as a major conversion and all country, all technology, all sub technology, we have taken. All the sub-technologies are here. So, this is the graph; it came up with. So, here we are going to only highlight solar thermal and solar PV. Solar PV, it is around 549,833 gigawatt hour. For solar thermal, it is 12,200 gigawatt hour

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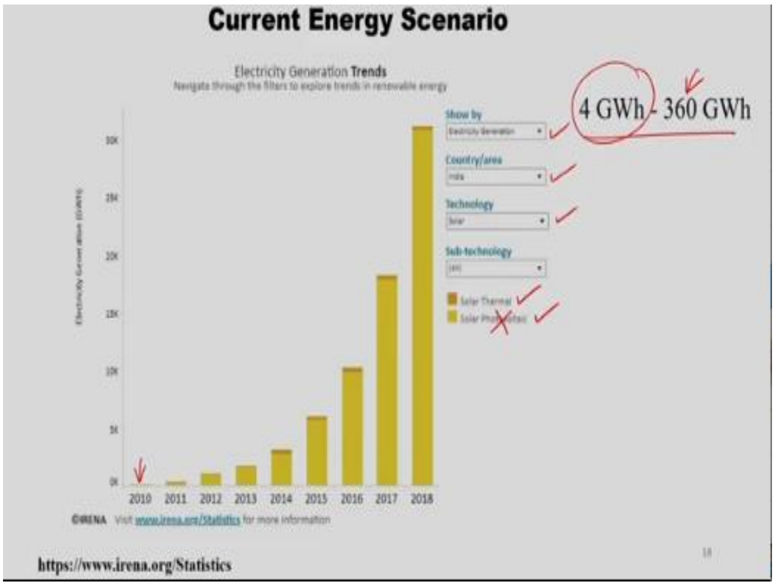

And we also have checked this with electrical generation in India with the solar technology sub-technology both solar thermal and solar photovoltaic. Since we are not considering solar photovoltaic. So, we came up with the number in only for solar thermal. So, that is 4 gigawatt hour in around 2010. It got increased to 360 gigawatt hour in 2018. So, this is in terms of electricity generation.

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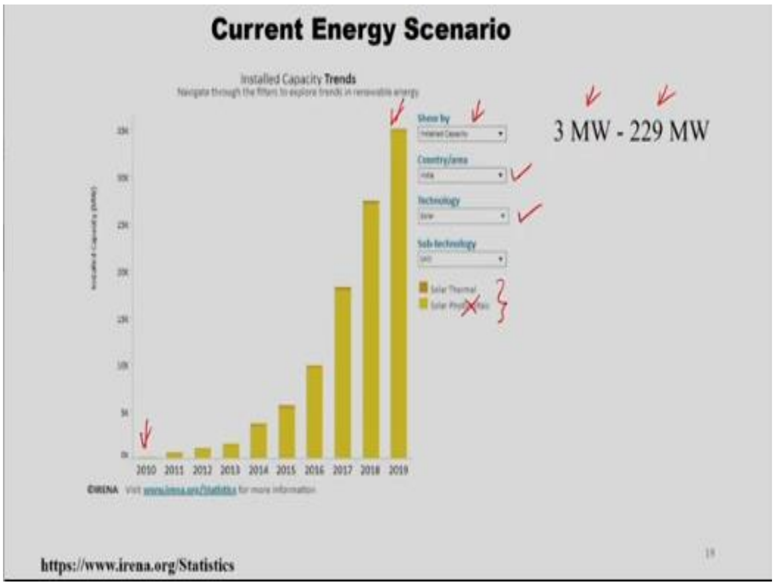

And in terms of installed capacity again in India in solar technology both sub technology and we have not come up with the numbers for solar photovoltaic. Obviously you can see here that is a major part but since we are interested in solar thermal, we came up with numbers for solar thermal. So, 3 megawatt in around 2010 and 229 megawatt in 2019. So, this is the current energy scenario in terms of solar thermal for installed capacity as well as for electricity generation.

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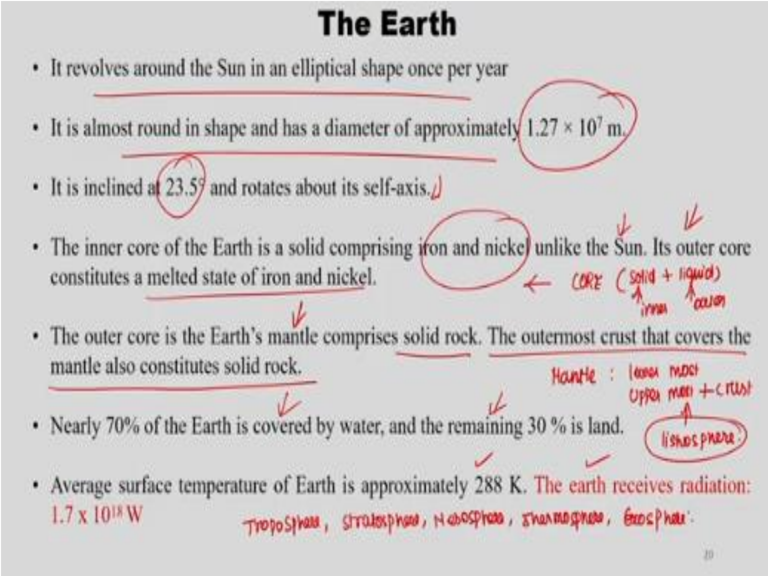

And then before moving into thermal applications, we will review few facts about earth and sun and their geometric relationship because to get to know about solar radiation. So, we might be in need of certain informations. So, the earth revolves around the sun in an elliptical shape once per year and it is almost round and shape and has a diameter of approximately 1.27 into 10 to the power of 7 meter.

It is inclined at an angle of 23.5 degree and rotates about its self-axis. Alright. So, the inner core of the earth is solid comprising of iron and nickel unlike the sun. So, sun, it is nothing but we call it as a helium. So, fusion reaction of hydrogen atoms into helium anyway that we will discuss. So, its outer core of the earth constitutes of melted state of iron and nickel. So, this both comprise of the region core we call it as.

So, inner core is solid and then outer core the melted state that is in liquid state. So, this is inner core. So, this is outer core. Then there comes the earth's mantle. So, the outer core of earth mantle comprises of solid rock. The outermost is crust that covers the mantle also constitutes a solid cover. So, earth mantle also you have in the mantle. So, you have two sections. One is the lower most and then uppermost.

So, this uppermost with the crust both of them together called lithosphere. Then after that above than that you will have the ocean and then land part and then nearly 70 percentage of earth is covered by water and remaining 30 percentages is land. Average surface temperature of the earth is around 288 Kelvin and earth receives radiation of about 1.7 into 10 to the power of 18 watt.

So, this uppermost mantle and crust forms the lithosphere then after that after lithosphere, there is a troposphere. Then after troposphere, there is a stratosphere. Then after that mesosphere, then thermosphere, then exosphere. So, that is outermost part of the earth.

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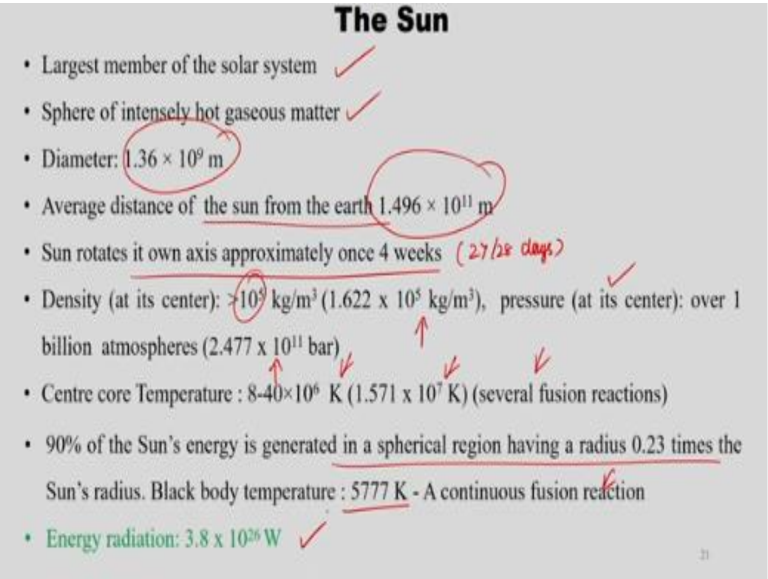

And then the sun which is largest member of the solar system. So, they are intensely hot gaseous matter. The diameter is 1.36 into 10 to the power of 9 meter. The average distance of the sun from the earth is around 1.496 into 10 to the power of 11 meter. The sun rotates its own axis approximately once in 4 weeks. So, we call it as 27 or 28 days. So, density at its centre is around 10 to the power of 5 kilo grams per meter cube greater than.

So, certain NASA models protects it as 1.622 into 10 to the power of 5 kg per meter cube and pressure at its centre is around over 1 billion atmosphere and again the model predicts it as 2.477 into 10 to the power of 11 bar. The central core temperature is around 8 to 40 into 10 to the power of 6 Kelvin. So, the model predicts it as 1.571 into 10 to the power of 7 Kelvin due to several fusion reactions.

90 percentage of sun's energy is generated in the spherical region having radius of 0.23 times the sun's radius. The black body temperature is 5777 Kelvin due to continuous fusion reaction. Energy radiation is around 3.8 into 10 to the power of 26 watts.

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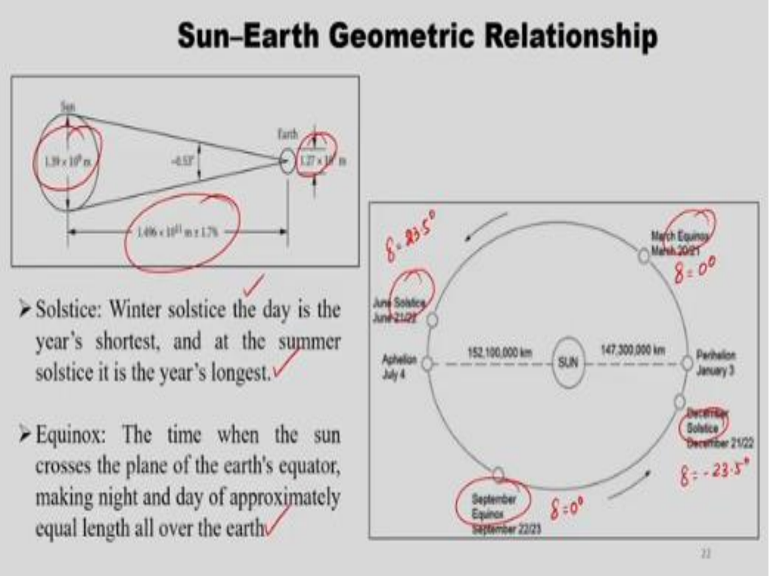

So, this is diameter of the sun, diameter of the earth and then their distance. So, here we have the sun and earth's rotation. So, how we get two solstice. One in December and another in June and then two equinox days. One in March and another is in September. Winter solstice is the day which is the shortest day of the year and at the summer solstice it is the year's longest day.

Equinox is the time when the sun crosses the plane of earth's equator making night and day of approximately equal length all over the year. So, that is two equinox we get on March and September. So, where your declination angle of the sun becomes 0 degree and in June solstice what you get is declination angle is 23.5 degree and in December what you get is minus 23.5 degree.

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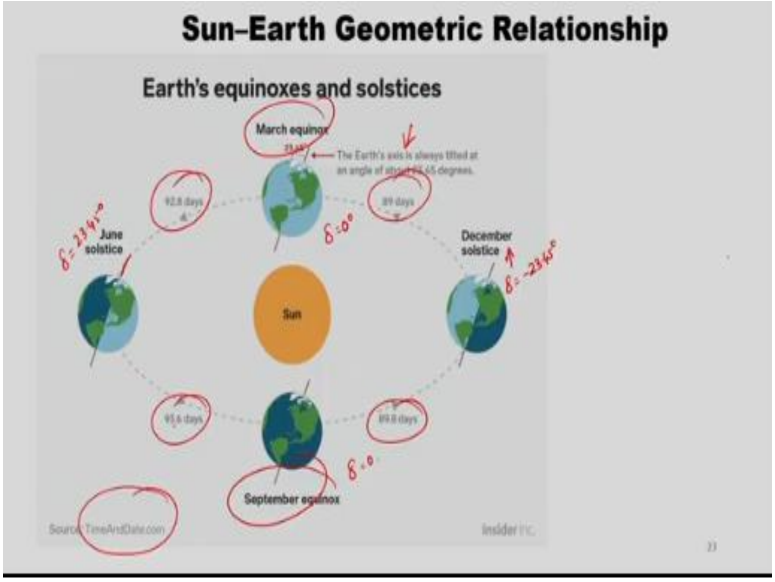

So, this is this particular figure is taken at TimeAndDate.com. So, here you can see the March equinox and September equinox whatever we told here. So, where your declination angle is 0. And this is the earth's axis is always tilted at an angle of about 23.45 degrees and these two are December and June solstice like this is 23.45 so, if you see. So, this is December solstice. So, here your declination angle is minus 23.45 degree.

So, here this December to March, you would get 89 days and this equinox 2, this solstice you will get 89.8 days and this side from March equinox to June solstice you will get 92.8 days and from June solstice to September equinox, you would get 93.6 days.

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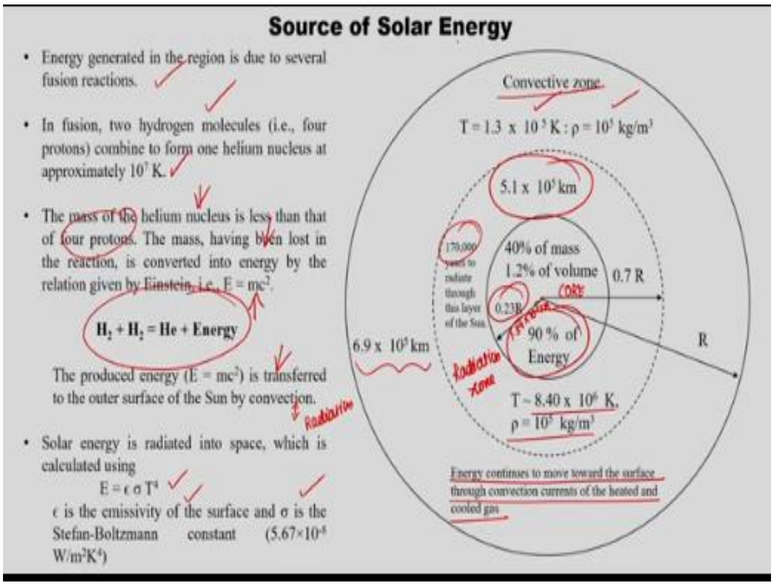

Then the source of solar energy as we discussed already around 0.23 r. This is nothing but a inner core of the sun. So, 90 percentage of the energy is produced over here. So, from the centre so, this distance the core distance is around 1.39 into 10 to the power of 5 kilo meter. So, 90 percentage of the energy is produced here. So, that we are going to see how. The energy generated in the region is due to several fusion reactions.

In fusion, two hydrogen molecules combine to form 1 helium nucleus at approximately 10 to the power of 7 Kelvin temperature. The mass of helium nucleus is less than that of the 4 protons which is fusioned to give helium and this mass having been lost in the reaction is converted into energy by the relation given by Einstein, E equal to m c square. So, this is that particular reaction when two hydrogen atoms are being fusioned to get helium.

So, this is the way it is predicted what is happening inside the sun. The produced energy is transferred to the outer surface of the sun by convection. The second layer is nothing but radiation and then by convection. The solar energy is radiated into space which is calculated as epsilon sigma t to the power of 4. So, epsilon is nothing but emissivity of the surface. Sigma is nothing but Stefan-Boltzmann constant which is 5.67 into 10 to the power of minus 8 watt per meter square Kelvin power 4.

So, coming back to here the next zone is nothing but a radiation zone. So, here almost 170,000 years to radiate through this layer of the sun. So, this radiation zone to cross. So, it takes almost 170,000 years and this distance from the core of the sun is about 5.1 into 10 to the power of 5 kilometer. The temperature is around 8.4 into 10 to the power of 6 Kelvin and the density is about 10 to the power of 5 kilo grams per meter cube.

So, this spreads over almost 0.7 of total radius of the sun. The outermost region is nothing but a convective zone. So, in this zone energy continues to move toward the surface through the convection currents of heated and cold gas. This length is around 6.9 into 10 to the power of 5 kilometer. The temperature is about 1.3 into 10 to the power of 5 Kelvin and density is about 10 to the power of 5 kilograms per meter.

Then after this so, this constitutes a sun inner core region and then radiative region and then convective region.

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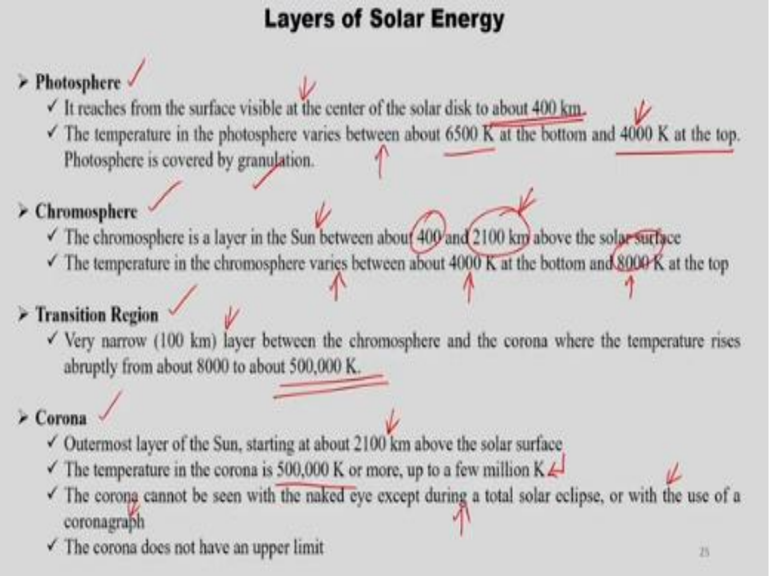

Then after that we will have this photosphere, chromosphere, transition region and corona. In the photosphere, it reaches from the surface visible at the centre of the solar disk. So, that is this particular surface. So, to about 400 kilometer it spreads over. The temperature in this region is between about 6500 Kelvin at the bottom to 4000 Kelvin at the top. So, that means so, from this surface when it spreads over outer region.

So, the temperature is decreased and this is covered by granulation. The next layer is chromosphere. So, it is a layer in the sun between 400 to 2100 kilometer above the solar surface. The temperature in the chromosphere varies between about 4000 Kelvin at the bottom to 8000 Kelvin at the top. So, that means inner part is lesser temperature; outer part is higher temperature.

So, that means when it spreads over the outer surface its temperature is increasing. So, the transition region is very narrow region between chromosphere and corona where the temperature rises abruptly from 8000 Kelvin to 500,000 Kelvin. So, the outermost layer of the sun starting at about 2100 kilometer above the solar surface. The temperature in the coronal layer is 500,000 Kelvin or more up to few million Kelvin.

The corona cannot be seen with the naked eye except during total solar eclipse or with the help of that coronagraph. The corona does not have an upper limit. So, it it spreads over.

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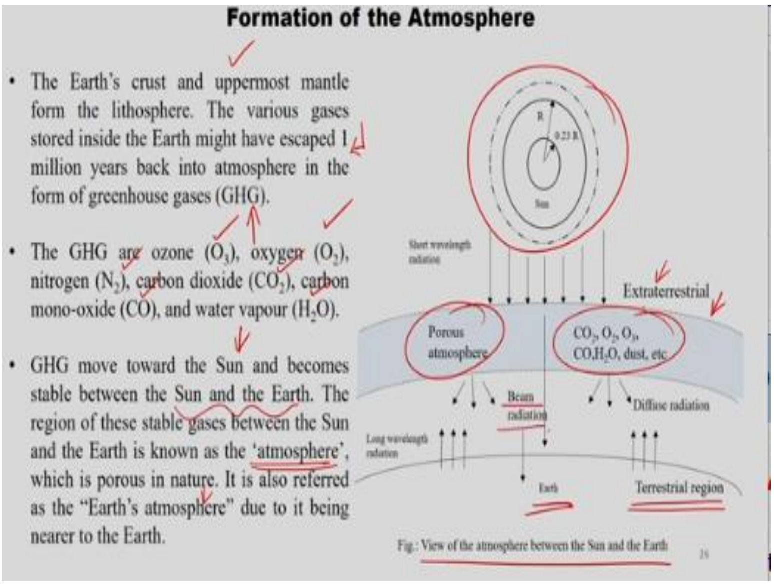

So, then the formation of the atmosphere. So, this is nothing but our sun. So, the sun and this is nothing but earth's surface. So, this we call it as the lower surface of the earth. We call it as a terrestrial region. The upper limit of this atmosphere is nothing but extra terrestrial region. Right . So, now here the earth's crust and uppermost mantle forms the lithosphere. This we already discussed.

So, the various gases stored inside the earth might have escaped 1 million years back into atmosphere in the form of greenhouse gases. So, the ozone, oxygen, nitrogen, carbon dioxide, carbon monoxide and water vapour everything forms together as a greenhouse gases. So, they move towards the sun and becomes stable between sun and earth. So, this region is called atmosphere.

Where this gases are there between sun and earth which is porous in nature it also referred as the earth's atmosphere due to its being nearer to the earth. Because it is nearer to earth, it is called as earth's atmosphere. So, this is the view of atmosphere between sun and earth. So, this is nothing but porous atmosphere where we have GHG greenhouse gases. So, these are the reason for the sun's radiation to get diffuse.

And reaches the earth and the radiation which are not absorbed or scattered through these gases directly reaches the earth that we call it as a beam radiation.

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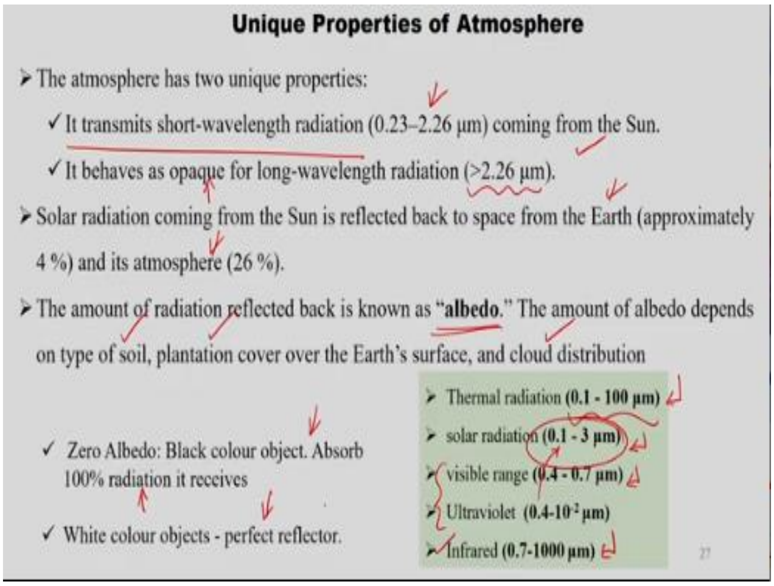

Then certain unique properties of atmosphere hit atmosphere transmits the short wavelength radiation which is about 0.23 to 2.26 micrometer coming from the sun and it behaves opaque or not transparent for long wave radiation which is greater than 2.26 micrometer. Solar radiation coming from the sun is reflected back to the space from the earth of approximately 4 percentage and its atmosphere is about 26 percentage.

The amount of radiation reflected back we call it as albedo. The amount of albedo depends on types of soil plantation cover over the earth's surface and cloud distribution. So, here if we see the various radiation and the wavelength is given. So, for thermal radiation is, it is about 0.1 to 100 micrometer but solar so, this is what we are interested in 0.1 to 3 micrometer. Visible range comes 0.4 to 0.7 micrometer.

And in that ultraviolet range also comes I mean this solar radiation both visible range that is totally into it and ultraviolet spans from 0.4 to 10 to the power of minus 2 micrometer. So, this also some part comes in solar radiation. And infrared spans between 0.7 to 1000 micrometer. So, this also comes here in the solar radiation. And if the object has zero albedo, so, that is nothing but a black colour object.

It can absorb 100 percentage of the radiation as it receives and white colour objects are considered as a higher albedo objects. So, they are the perfect reflectors.

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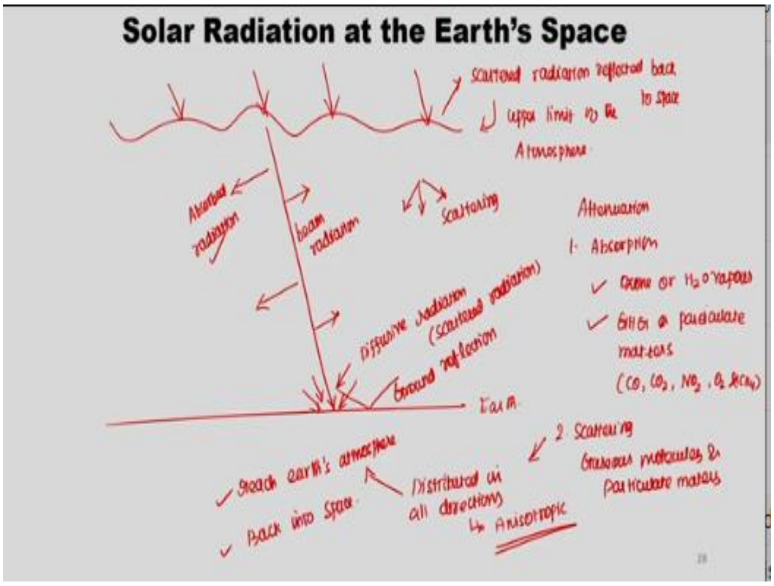

So, this is solar radiation at the earth's surface. So, if we consider, this is the upper limit of the atmosphere and this is earth. So, we get the solar radiation as we said already. So, the beam radiation reaches directly. Sometimes it gets absorbed as well. This is observed. This is absorbed radiation and there may be a scattering here. So, in that way the diffusive radiation also reaches.

So, this is diffusive radiation or we call it as a scattered radiation and there may be radiation which is ground reflection due to ground reflection as well. And some of the radiation goes back to space; scattered radiation reflected back to space. So, this is overall picture of solar radiation at the earth's surface. So, as we said the solar energy when it reaches the earth, there may be attenuation.

So, that is due to absorption as we said here. So, this happens either by ozone or water vapour. Again they are coming under greenhouse gases only. And to the lesser extent the other greenhouse gases and particulate matters. So, those are CO, CO2, NO2, O2 and CH4. And then the scattering so, one is by absorption; the second is by scattering. So, the scattering happens due to gaseous molecules again and particulate matters.

So, these are distributed in all directions. So, in that way, we may not expect; it is uniform from all directions. So, we call it as an isotropic but certain models consider them as a isotropic in nature as well. And this distributed can be reached; can reach earth's atmosphere or they can go back to space as well; back into space as well.

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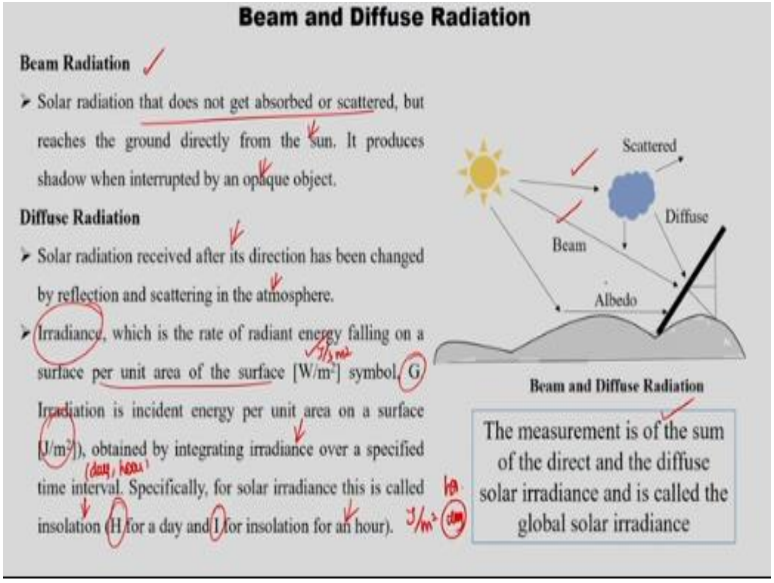

So, the beam radiation that we have just seen the solar radiation that does not get absorbed or scattered. So, but reaches the ground directly from the sun. It produces shadow when interrupted by an opaque object. The diffusive radiation is the one; the solar radiation received after its direction has been changed by reflection and scattering in the atmosphere.

Usually, we follow certain the terminologies irradiance which is the rate of radiant energy falling on a surface per unit area of the surface that is watt per meter square. Symbol is G. And irradiation is the incident energy per unit area on a surface that is Joule per meter square. So, here Joule per second meter square. So, if we take instant energy that is Joule per meter square obtained by integrating a irradiance over a specified time interval.

We can do it by day or we can do it per hour and the second if you are doing that is instant then specifically for solar irradiance. This is called insulation. So, if you integrate it over a day or hour, this is called insulation. So, we use the symbol H for a day and I for a insulation for an hour. So, it can be given as watt per meter square as a flux which is nothing but radiant energy falling on a surface per unit area or we can give them in terms of Joules per meter square day or hour instead of joule per second meter square.

So, the measurement of some of the direct and diffusive radiation is called the global solar irradiance. So, this is beam and this is scattered diffusive radiation. This is albedo. Either it can reach earth's surface or it can go back to space as well.

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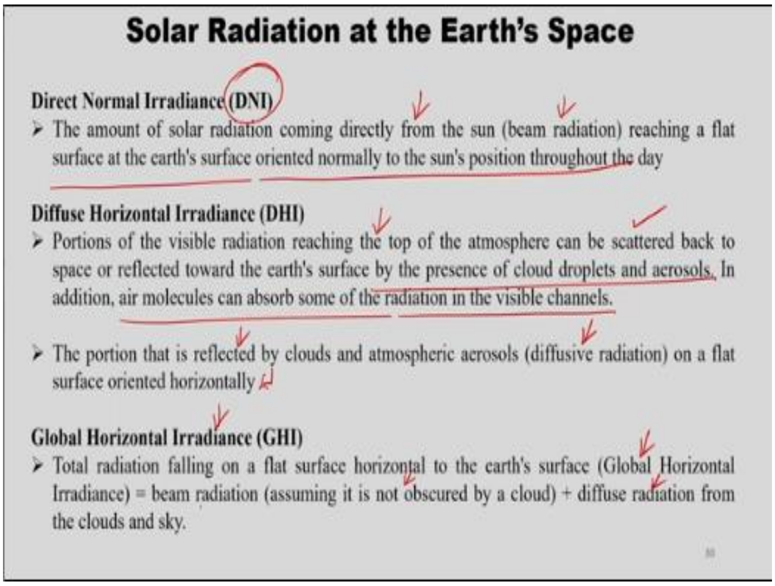

So, this is the important term DNI in solar radiation at the earth's surface. The amount of solar radiation coming directly from the sun which is called as beam radiation reaching a flat surface at the earth's surface oriented normally to the sun's position throughout the day that is called direct normal irradiance.

The portions of the visible radiation reaching the top of the atmosphere can be scattered back to a space or reflected towards the earth's surface by the presence of cloud particles and aerosols. So, in addition air molecules can absorb some of the radiation in the visible channels as well. So, either scattered or absorbed. So, this portion that is reflected by clouds or atmospheric aerosols.

We call them as diffusive radiation on a flat surface oriented horizontally. So, that is what it is called diffuse horizontal radiance. Then global horizontal irradiance is nothing but total radiation falling on a flat surface horizontal to the edge surface that is global horizontal irradiance is nothing but beam radiation assuming it is not obscured by cloud and diffuse radiation from the clouds and sky.

So, this is DNI which is nothing but direct normal irradiance and diffuse horizontal irradiance and then global horizontal irradiance proper definitions.

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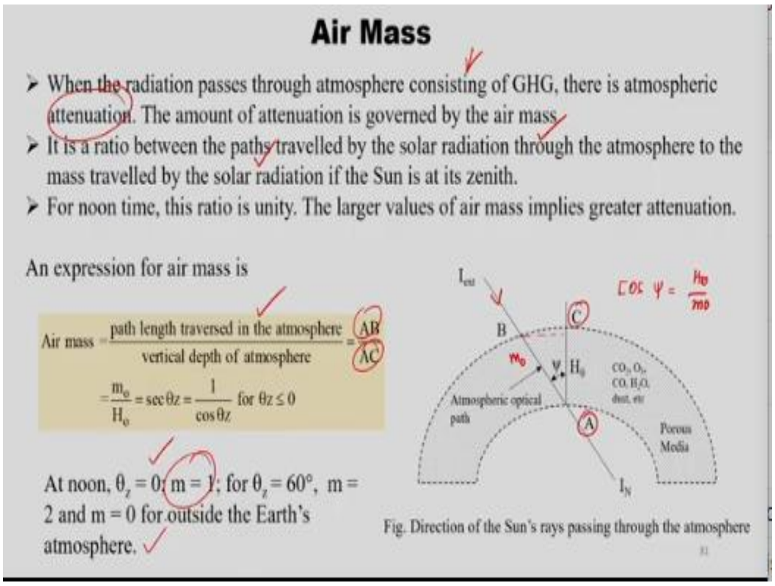

Then the next one is nothing but air mass. So, when the radiation passes through the atmosphere consisting of greenhouse gases. There is a atmosphere attenuation happens. The amount of attenuation is governed by the air mass. So, this attenuation is nothing but the decrease in energy. So, the ratio between the paths travelled by the solar radiation through the atmosphere to the mass travelled by the solar radiation if the sun is at its zenith.

So, when sun is at zenith then the position is A and C. When the path travelled by the solar radiation through the atmosphere to the mass travelled by the solar radiation if the sun is at its zenith. So, AC is sun at zenith. AB is nothing but the path travelled. So, path length traversed in the atmosphere that is AB and vertical depth of the atmosphere is AC. So, if we take cos of the angle, right, so, that is nothing but H 0 upon m 0.

So, if we want to calculate m 0, so, this distance is; AB is m 0. AC is H 0. So, if we want to calculate m 0 upon H 0 that is 1 by cos theta z. That is sec theta z. For all, theta is at less than or equal to 0. At noon we will have theta z as 0, there your air mass is 1. For theta z is 60 then we will get air masses 2 and if for m equal to 0 for outside the earth's surface.

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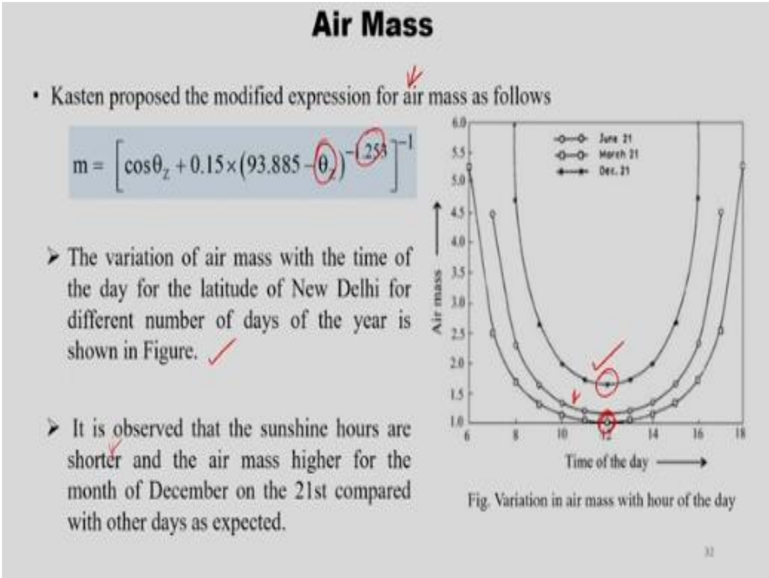

And here if we see the another expression given by Castin so, which has satin constants and zenith angle as well. The variation of the air most with the time of the day for the latitude of New Delhi for different number of days of the year is given here. So, here if we see the December 21st, so, this particular figure. So, your air mass is very much high. So, it is observed that sunshine hours are shorter and the air mass higher for the month of December on 21st compared to other days.

So, December 21st we will get lesser sunshine hours. So, obviously air mass is higher. So, then followed by June and if we see the March time, we will attend time of the day around 12 noon; the air mass is 1. So, you will get less air mass.

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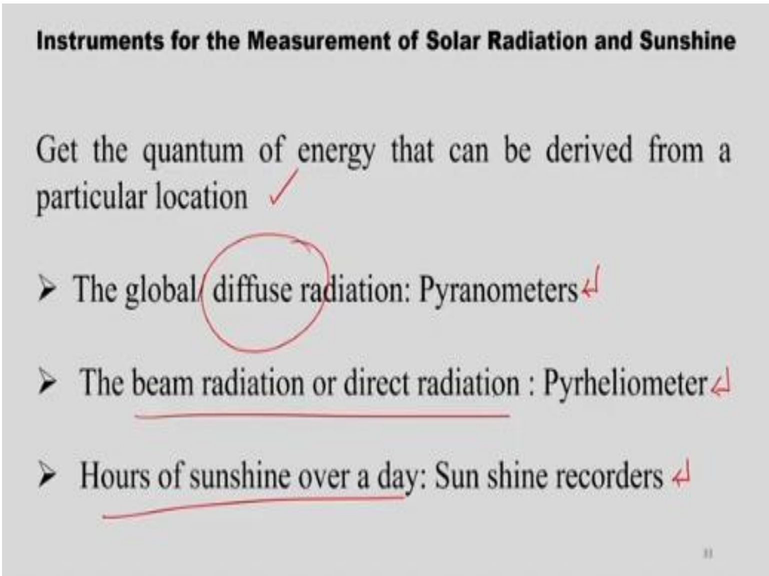

Then next one is instrument for measurement of solar radiation and sunshine. So, we will get the quantum of energy that can be derived from a particular location in terms of 3 quantities. One is global or diffusive radiation and then beam radiation or direct radiation and hours of sunshine over the day. So, these three quantities we can measure and what are all the equipments used for this measurement.

One is Pyranometers. The second one is Pyrheliometer and then sunshine recorders. We are going to discuss each one of them in subsequent slides.

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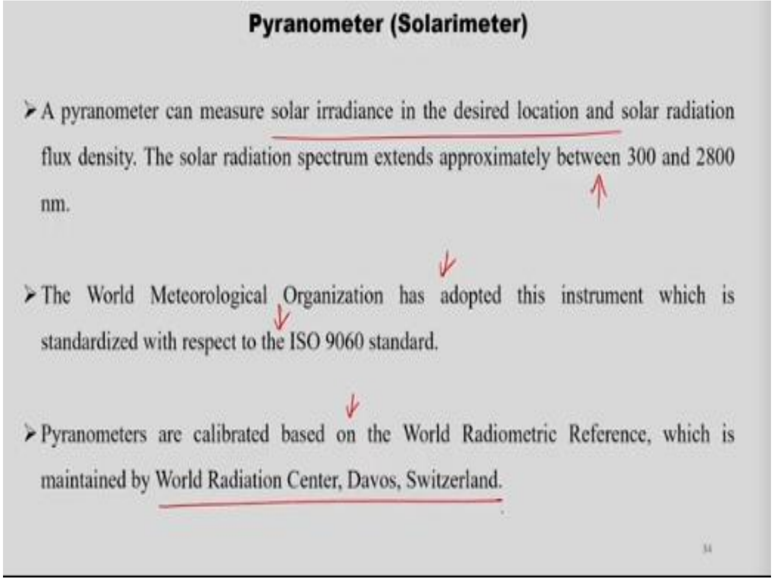

The first one is Pyranometer. We can call it as a Solarimeter. So, this is used to measure the solar irradiance in the desired location and solar radiation flux density. So, this solar spectrum almost extends between 300 to 2800 nanometer. So, this World Meteorological Organization WMO has adopted this instrument which is standardized with respect to ISO 9060 standard.

And Pyranometers are calibrated based on the World Radiometric Reference which is maintained by World Radiation Center, Davos, Switzerland. So, in that way it is calibrated properly to measure the solar irradiance data.

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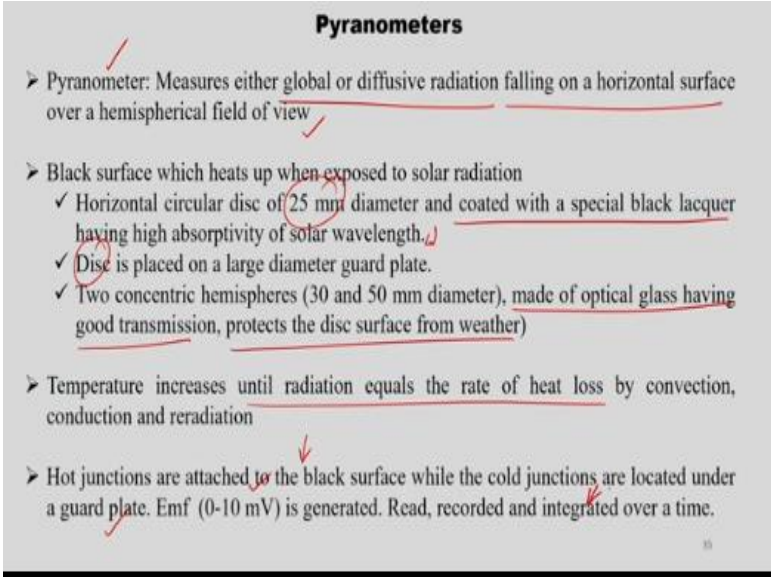

And then Pyranometer which measures the either global or diffusive radiation. Global radiation, we can directly measure. Diffusive means then we need to do certain arrangements to stop the beam radiation. So, which falls on the horizontal surface over a hemispherical field of view. So, here we have these 3 major parts. One is horizontal circular disc of 25 millimetre diameter coated with the special black lacquer having high absorptivity of solar wavelength.

And then there is a Disc which is placed on a larger diameter guard plate and two concentrated hemispheres which are made of optical glass having good transmission and protects the disc surface from weather. So, here if you see these are those the glass dooms. So, this is nothing but black surface and this is nothing but a guard plate. The temperature increases until the radiation equals the rate of heat loss by convection and conduction and radiation.

And hot junctions of the thermopile material which are attached to one end is attached to black surface. Another end which is cold junction which is located under the guard plate. So, Emf generator of about 0 to 10 millivolt is recorded. So, it is read, recorded and integrated over the time if you want to have it for a day or for an hour. So, this is the particular arrangements.

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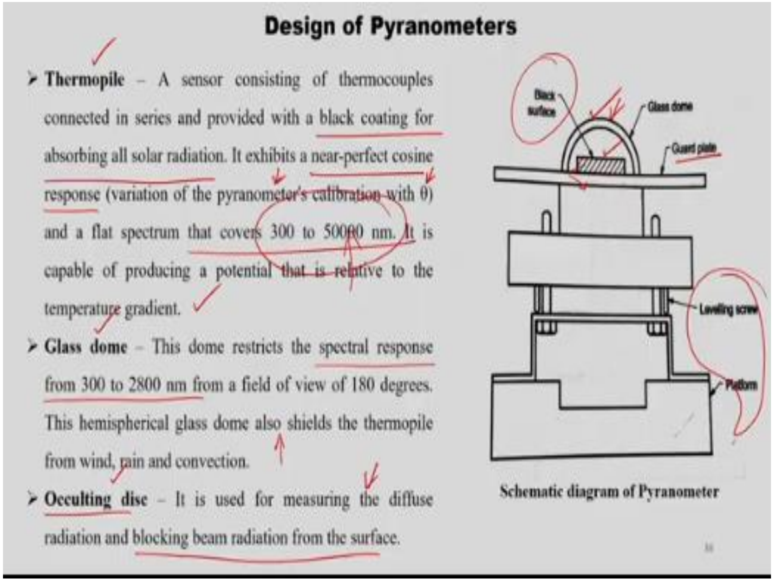

So, here we have levelling screw and platforms to keep it in particular position against the sun's radiation. The sensor thermopile, glass dome and occulting disc, the sensor consisting of thermocouples connected and series provided with a black coating for absorbing all solar radiation. It exhibits near perfect cosine response which is nothing but a variation of Pyranometers calibration with theta.

Theta is nothing but angle of incidence and a flat spectrum that covers 300 to 50000 nanometer that is solar spectrum. It is capable of producing potential that is related to the temperature gradient. It is nothing here we have black surface so, which absorbs the radiation. So, the thermopile material is connected. One end is here in the black surface. Another end is the guard plate. It is considered as a cold junction.

And then there is a glass dome which is this one because we are considering here the total radiation, right total solar radiation but this dome restricts the spectral response from 300 to 2800 nanometer from a field view of 180 degree and its function is not only this. This hemispherical glass dome also shields the thermopile from wind, rain and other environmental factors.

But here we said that we will measure the global radiation using this particular Pyranometer. If we want to measure only diffusive radiation then we use occulting disc. So, this is used to measure the diffusive radiation and it blocks the beam radiation from the surface.

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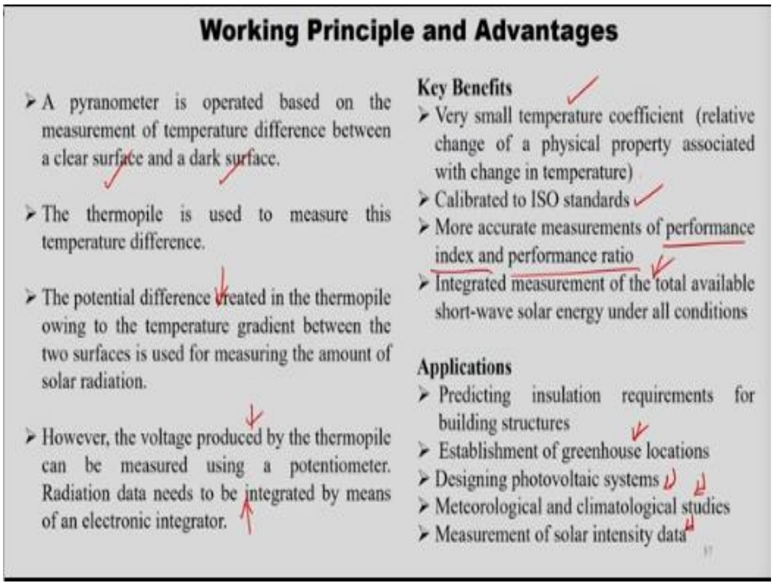

So, here the conversion is whatever the temperature difference created between the clear surface which is guard plate and the dark surface is converted into potential difference. So, then it is measured as a Emf and the voltage produced by thermopile can be measured using potentiometer. The radiation data needs to be integrated by means of electronic integrator if you want to have particular time period.

And very small temperature coefficient, temperature coefficient is nothing but relative change of physical property associate with the change in temperature that is Emf and then it is calibrated to ISO standards. Already we have told this. And performance index and performance ratios high for this particular equipment and we can get integrated measurements over total available short-wave solar radiation under all conditions.

Apart from predicting the diffusive or global radiation this can be used for some other applications. One is establishment of green house locations. We have already discussed the relation between solar radiation and GHG. And then designing photovoltaic system to get the radiation data and meteorological and climatical studies and measurement of solar intensity data.

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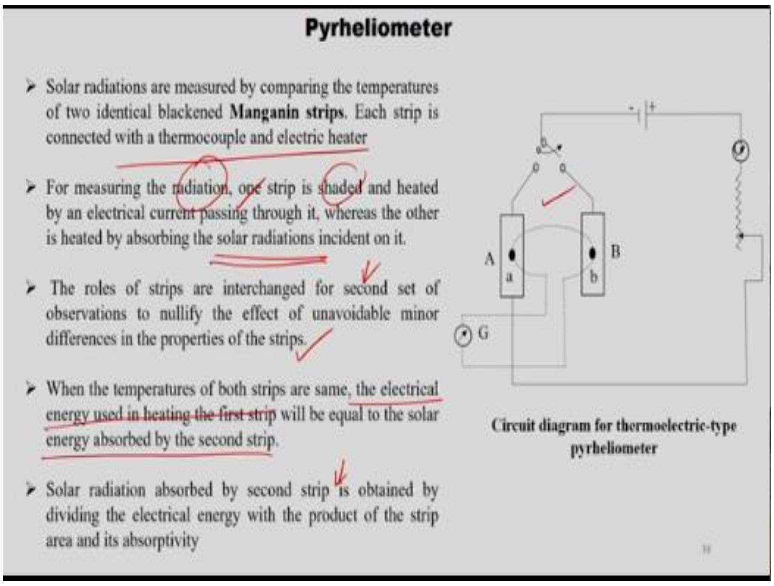

The next one is Pyrheliometer. So, here we have 2 Manganin strips. Each strip is connected with the thermocouple and electric heater. So, for measuring radiation, one strip is shaded and heated by an electrical current passing through it. One is electrical current. Other one is getting solar radiation directly. The roles of the strips are interchanged for second set of observation to nullify any effect of unavoidable minor differences there or not.

And then when the temperature of both strips are same, the electrical energy used in the heating the first strip will be equivalent to solar energy observed by the second strip. So, that is a basic working principle. We have 2 strips of Manganin material. So, one is connected to the electric heater. Another is with the solar radiation.

So, when the temperature is same for both, how much electrical energy we applied to the one strip that is equivalent to solar radiation which is fallen on the second step that is the working principle based on which Pyrheliometer works. So, then the second strip is obtained by dividing the electrical energy with the product of strip area and its absorptivity.

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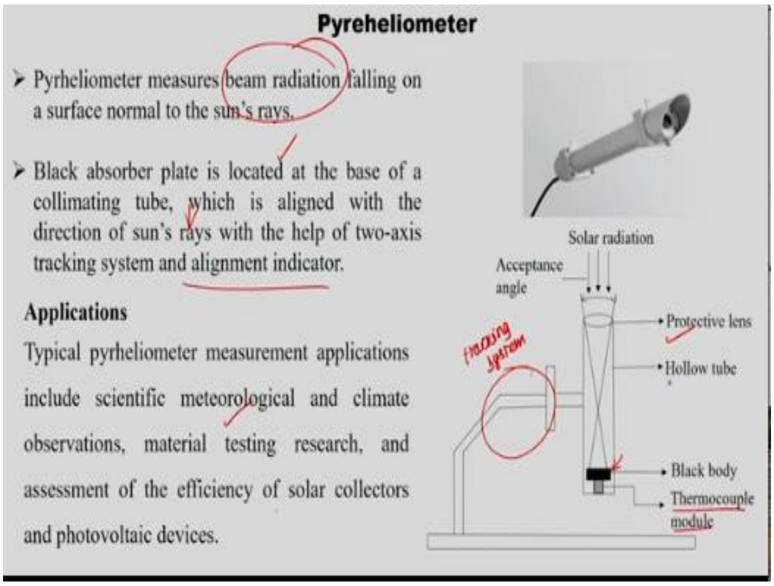

So, here it measures beam radiation falling on the surface normal to the sun's rays. Here the black surface plate, the black body is kept in the back side of the collimating tube which is aligned with the directions of sun's rays because it is going to measure only beam radiation with the help of 2 axis tracking system and alignment integrator. So, it is always ensured that it is aligned with the direction of the sun's rays.

So, this is protective lens and this is the collimating tube or hollow tube. The black body is kept here and this is the thermocouple module. One is kept in black body. Another is in with the clear surface. So, this is the axis system tracking, tracking system. So, with which we can measure the beam radiation. The application is again it is used for meteorological and climatic observations and material testing research and then assessment of efficiency of solar collectors and photovoltaic devices.

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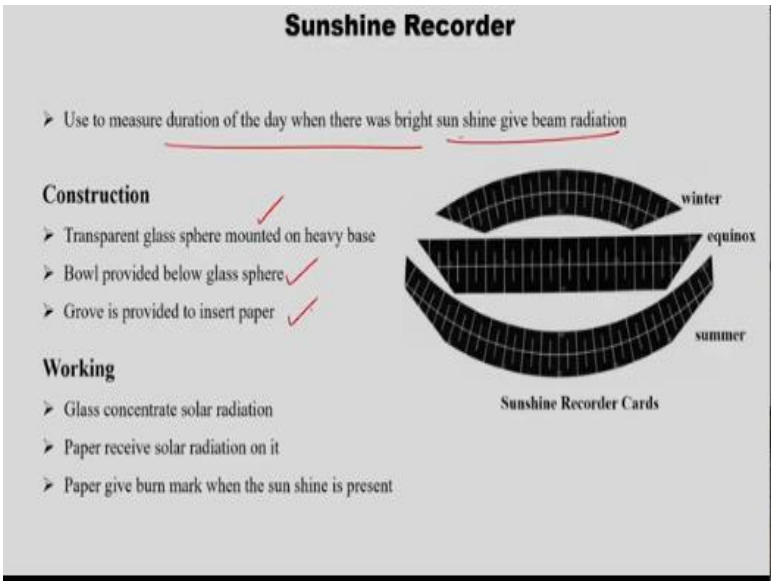

Then sunshine recorder used to measure the duration of the day when there was a bright sunshine give beam radiation and its construction is transparent glass sphere mounted on a heavy base and then one bowl which is provided below the glass sphere and groove is provided to insert the paper.

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So, here it is. So, this is the spear and then the bowl below the glass pier and then groove is provided to insert the paper. So, this is that particular space where your paper is kept and then working is the glass concentrate the solar radiation and paper receive the solar radiation on it and paper give burn mark when the sunshine is present. So, for winter we have small cards, small length cards and equinox in the medium sized and summer one, we have long cards. This is sunshine recorder cards.

So, those were kept here in this place and this is an instrument for measuring duration of bright sunshine in hours. It consists of glass sphere that we already said and which is in a section of spherical brass ball which grooves to hold the recorder cards. So, that is this arrangement and the spear burns the trace on the card after being exposed to the sun.

The length of the trace is nothing but the direct measurement of duration of bright sunshine hours and a long curved card for summer as we said. Long curved card for summer and short one for winter and then straight cards for equinoxes.

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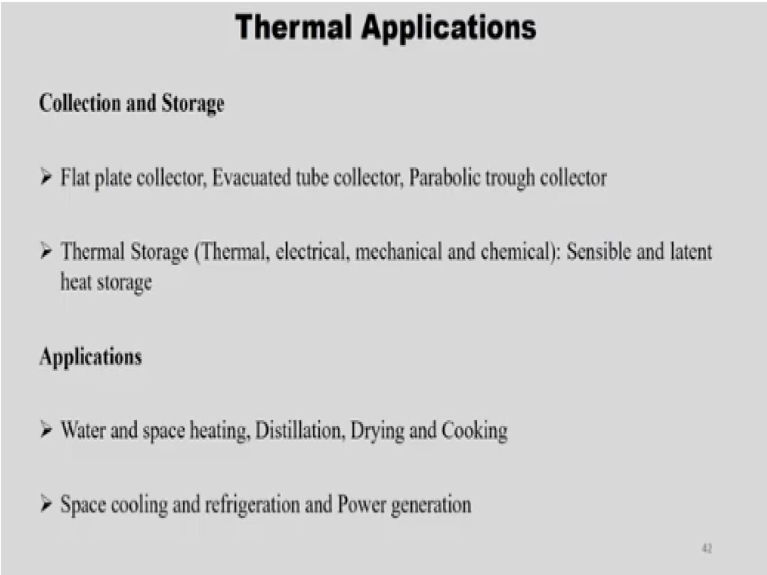

And then thermal applications that we will discuss in tomorrow's class and then continue to go about the solar radiation.

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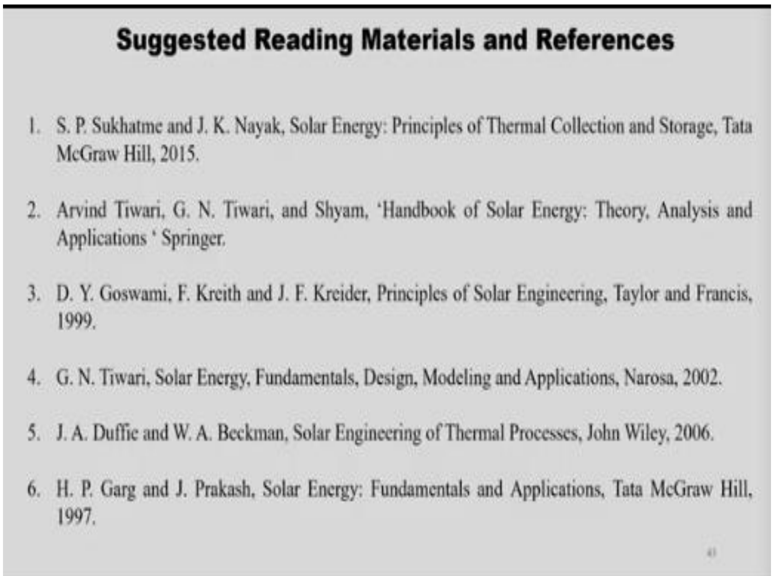

And these are all the references and reading materials. We would be using for this particular lecture as well as the lecture number 2 solar radiation. Thank you.