Introduction to Atmospheric Science
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Lecture – 30
Clausius Clapeyron Relation (Contd.)

So in the last class, we looked at the Clausius Clapeyron equation which is the first latent heat equation. I promise you that we will start radiative transfer, yes we are going to start radiative transfer, but I felt that second law of thermodynamics, Clausius Clapeyron everything was too fast maybe we should solve a problem to slow as down also understand things better. So we will solve a problem involving the Clausius Clapeyron equation today for the first 10 to 15 minutes and then we will proceed to radiative transfer. What will be the new problem number? What is that?

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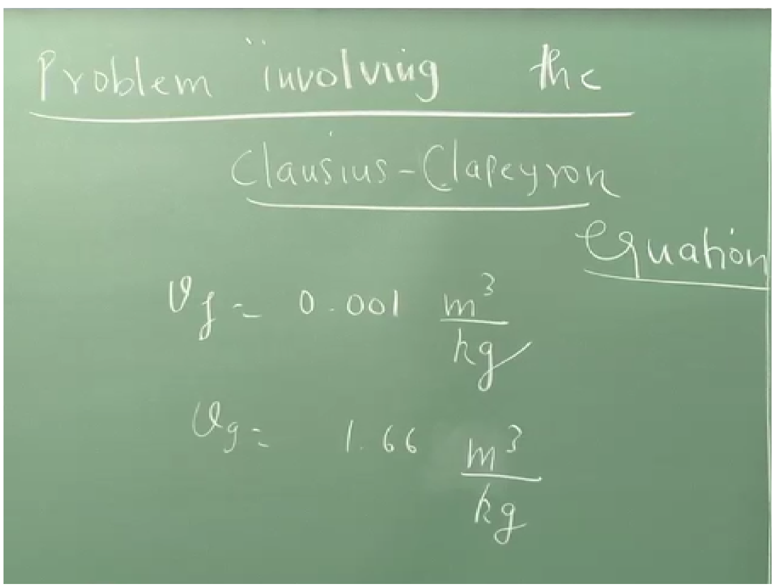

43. So problem number 43, let us take down the problem: Calculate the boiling point of water, problem number 43. Calculate the boiling point of water at the top of Mount Everest. You know the height, (z = 8, 848 meters). The specific volume of vapour is 1.66-meter cube per kg and the specific volume of liquid is 1 * 10 to the power of - 3 that is 0.001, the specific volume of the liquid is 1 * 10 to the power of - 3 or 0.001-meter cube per kg which is just like 1/rho where rho is 1000. Do not ask me where it is.

It is somewhere between the p0 and this vg and vf will also change with pressure, but then we will have to integrate and all that, let us not mess it up. So take some average value as vg and vf. Use a Clausius Clapeyron equation, change the d to del, which I did in the last class, take a couple of minutes so think about it, it is not straight, you cannot apply straight to the Clausius Clapeyron equation, some hidden fundas are there in this problem. Just think about it. I used to ask in quizzes earlier. Now I asked this so I cannot ask, so I have to look at a variant of this.

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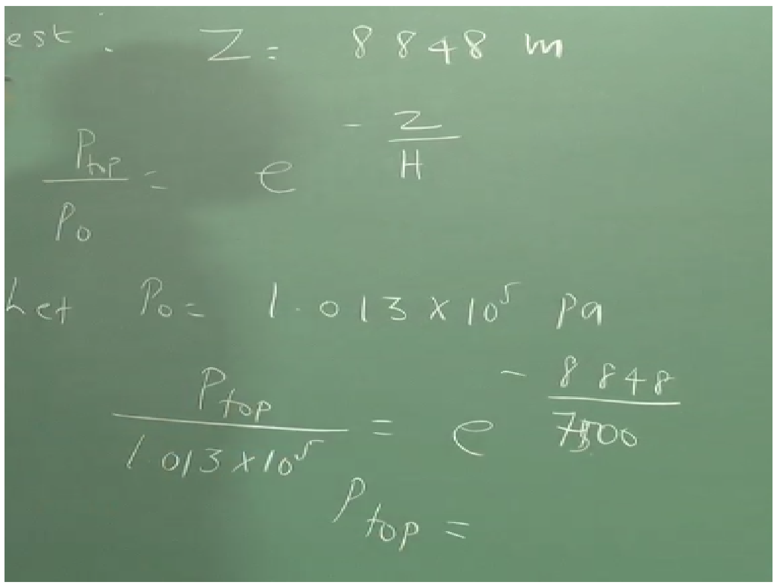

So the top of Mount Everest z is 8,848 meters so we can assume P0. Please tell me this value. 31.1 k Pa. So we assume a lapse rate to 5.5 what is the temperature at the top of the Everest? Now this is not required for this calculation, I want you do something.

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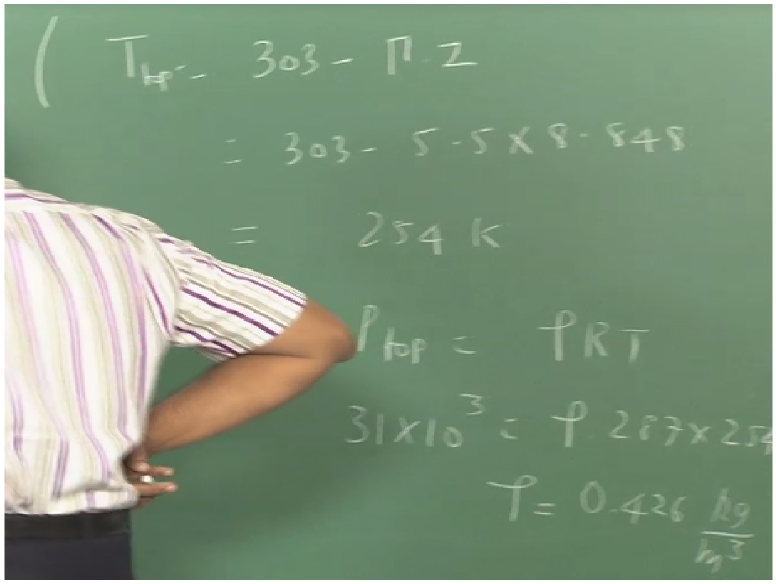

So T will be. What is rho? I will put in brackets it is not required for the problem. STp or ntp is 1.2 so got only 30% of the oxygen which is available at the sea level so we cannot so breathing is going to be extremely difficult. Once you cross 3000 or 4000 means you will get the high altitude sickness then enough oxygen which is reaching the brain, you will get headache and some people will go on the high altitude tricks and they did also.

You have heard young people will die so acclimatization if you go basically we just sleep off on a snow cap mountain the end of the sleep we may just die. So they should not sleep. So mountain climbing is very dizzy. So you got an idea. Why the window cannot be opened in an aeroplane? First of all, the aeroplane is 12 kilometer height it will be - 52 number 1, number 2 there is no oxygen. So always the cabin is pressurized. We saw that in a day but really if it brings it and all that then it will reach the potential temperature and people will be baked.

So it air-conditioning is also required. Cabin is always maintained I think 85% of normal pressure and it is maintained at 25 degree centigrade. Relative humidity is very low. So long distance flight some people get nasal bleeding and all that. The relative humidity is only 5%. So they want to preserve their upholstery see its this thing and all that and they do not want condensation and life of the aircraft and all. Aircraft air is very bad. So this is not our main story this is a side story. The main story is to get to the, what is that? Boiling point. Let us proceed with the.

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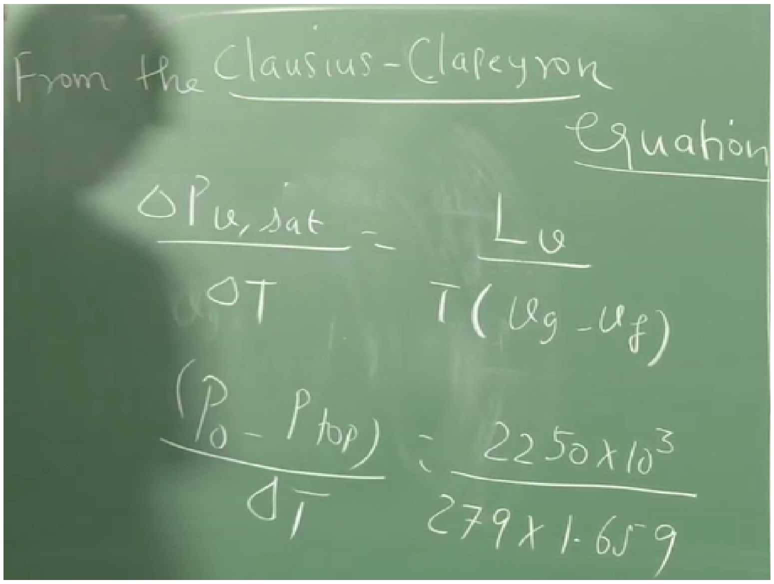

From the Clausius Clapeyron equation Lv * T or /T?. What I have written is correct. This T you can use an average T how much is it changing 303 to 254? So do you want to use an average T. You know might as well use now then know that you calculated so average is about 275, 280. Just calculate delta t.

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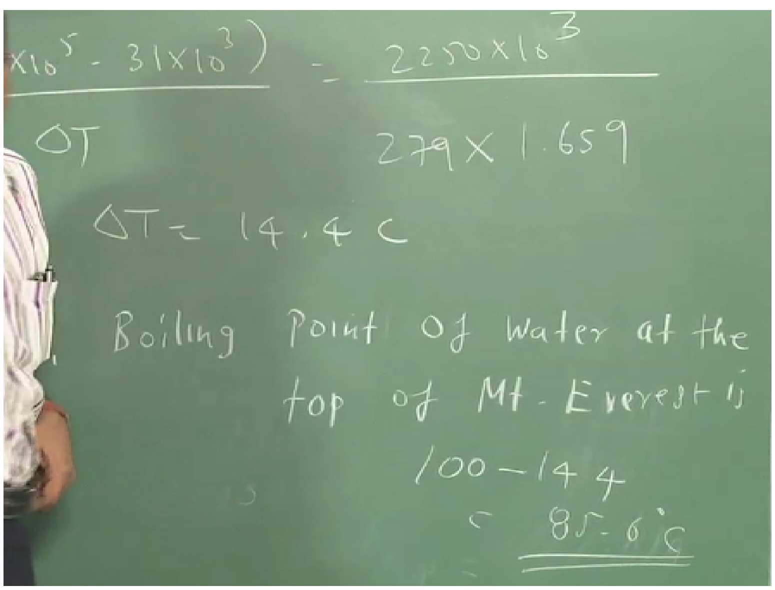

15. Yes somebody should that is, delta T is 14.4. So this delta T is nothing, but when the pressure is 1.013 10 to the power of 5, the boiling point is 100. So the pressure is 31 what is this. That defines the delta T. Is that okay? So this gives an idea of how to use the Clausius Clapeyron equation. Boiling point decreases with increasing height.

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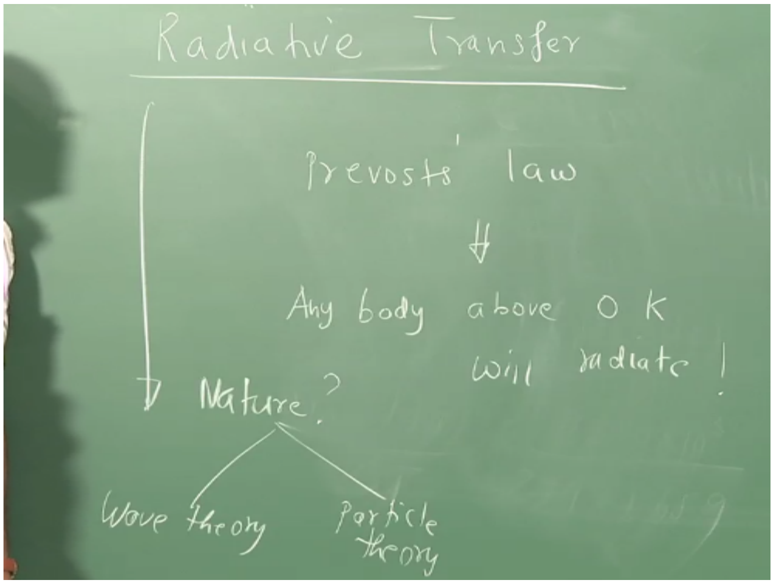

We go the next chapter Radiative transfer. Obviously, radiations is affecting us radiation is responsible for keeping us alive then we would not have such comfortable conditions outside. The sun's temperature, the sun's size, the earth's size and the distance between the sun and the earth and the reflectivity of the earth all these contribute to keeping the temperature between to 255 to 275 depending on black body assumption.

And so on which is responsible for the sustains of life. There is no need to prove that the sun's radiation reaches us that is why light is there and so on. We are always interested in day lighting and all the cool day lighting all this because it is natural for us to be comfortable with this. The first question we have to answer is why cannot bodies keep quite? Why are bodies radiating heat? Why cannot they just keep quite?

Then 1 problem less know conduction, convection, radiation only 2 more you have to study. Why another radiative transfer, quiz exam and some scientists are working, professors. **"Professor - student conversation starts"** You said something. Temperature is different. Everybody related to us have some temperature it vibrates body to that. If there is no temperature difference no radiation? It should be a whole absolute temperature.

Absolute temperature means where we find out what are you trying to say absolute zero. **"Professor - student conversation ends"** Anybody above 0 Kelvin will emit radiations because of the rotational translation, vibration energy of the molecules something called the molecular temperature. Because of this it cannot keep quite. So this is the fundamental of nature. It is called the Prevosts' law. Do not read it as anybody above ok will radiate.

Anybody > 0 Kelvin. Suppose you are fast sleeping take down the notes and then before exam what is sir, what sort of statement the sir given in the class. If you want to take 0 Kelvin it looks like okay gave some spacing. Anybody above 0 Kelvin will radiate. So what is the nature of this radiation? That means how do you characterize this are there any theories to characterize this? There are 2. You know that theory?

What are the theories you characterize radiation? Wave theory and particle theory. Wave theory is electromagnetic. They try to explain everything the wave theory because the wave theory comes on classical physics, but then the black body behaviour could not be explained using the wave theory it led to a dramatic failure at the hands of 2 most respected scientists of that time namely sir Rayleigh and Jeans and Rayleigh went on to get the Nobel prize and all that.

But he published the wrong distribution of black body behaviour. They did not give him for that for some other thing, but classical physics could not go beyond a certain point. Then they had to introduce this particle theory to explain the correct black body behaviour. So we will not say whether this is correct or which is correct, which is wrong that is unending debate whichever is suitable to us if we are able to explain a phenomenon using either of the 2 then it is okay with us. So because of the wave theory.

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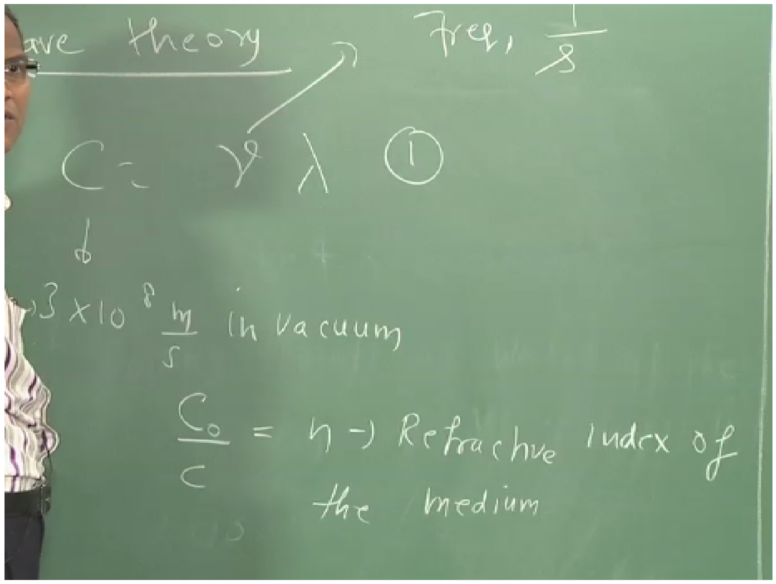

Somebody said even if you have to assume that there is no God sometimes to prove or disprove any it is necessary to invent one. It is good to have that so that we can explain many things. Like that we have both the wave and particle theory, but of course all these are verified by experiment and all that, okay. Wave theory C = nu lambda. C, the velocity, nu the frequency, lambda is the wavelength. 3 * 10 to the power of 8 meter per second in vacuum.

That is called C0. C0/C, refractive index. So this is frequency, 1/s. Please note that sec is not the SI unit of time. Sec is not the unit. Kg is not unit. Kg also small k, small g, capital k is Kelvin. Kgs and all there is no unit called kgs. It is 84 kg, it is not 84 kgs. Or you can say kilograms, but the abbreviated form cannot be pluralized, somebody taught you this.

Some professor might have taught you know in thermodynamics. Okay that does not matter now. Lambda basically the wave length though I would love to have it as meter, meter is too big for us. Normally we settle down with micrometer. So it gives you meters per second on the left hand side and.

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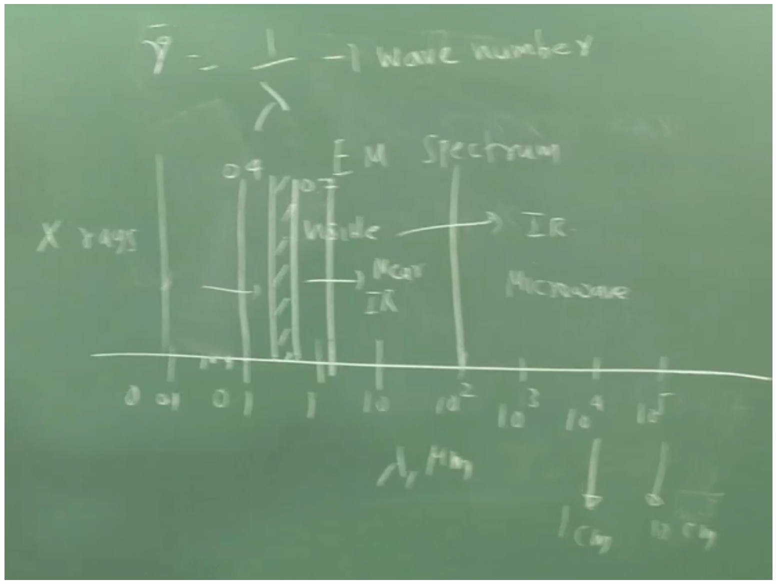

What is wave number is 1/lambda. Because of which you can have that is what I wanted to show the internet is not working. You have an electromagnetic spectrum. So this shows the decadal variation in wavelength. This is the lambda in micrometer. This is 1 cm. This is 10 cm. 0.4 to 0.7 micrometer is visible. No, I think I messed up. This is the visible part of the spectrum. 0.1 to 0.4 is ultraviolet.

Ultra is more but why is it called ultraviolet, it should be called infra violet the classification is based on the frequency rather than the wavelength. It should be infra-violet and ultra-red, but we call it as infrared and ultraviolet. Ultra is high. But somebody has classified based on frequency. So then 0.7 to 4 I think is called near IR infrared then this 4 to 100 is called infrared. Beyond this is called microwave. So x-rays will come somewhere here. Now, according to the particle theory.

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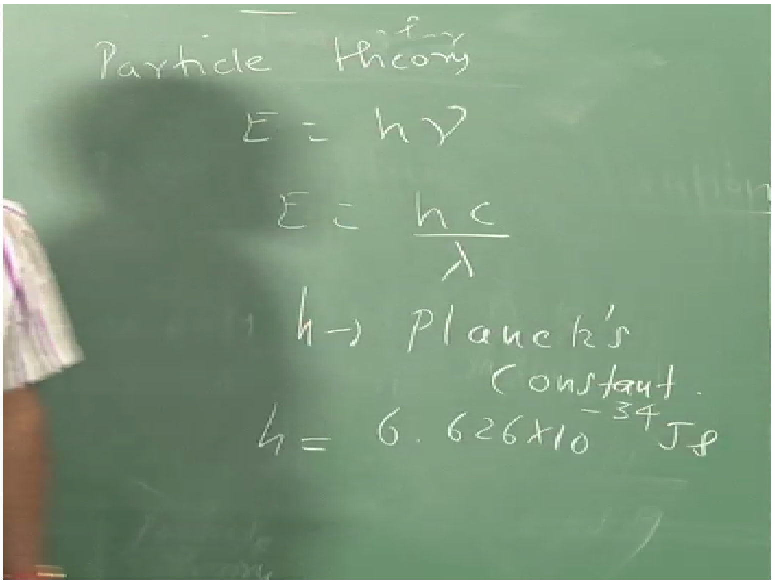

Based on the particle theory E = h nu the energy associated with the particular radiation. E = h * C/lambda. So when lambda is going like this mu is going like this. Increasing lambda is towards the right side and increasing nu is towards the left side. So very long wave radiation will have low energy, very short wave radiation will have high energy, E = h nu. So the x-rays have got high energy. The x-rays are of interest mostly to physicist.

At the other end of the spectrum we got microwave it is also of interest to atmospheric scientist, but of interest to communication engineers, electronic and communication engineers because they do long distance transmission of waves through this. Their energy is very low. So usually some modulation is done, amplitude modulation or frequency modulation. We have a signal + carrier wave then it is demodulated then it is broken down and this thing and you recover it.

So 1 side is physics and 1 side is electrical engineering, and mechanical engineers are in between and atmospheric scientists are also in between because for the range of temperatures we are interested only in some 0.1 to 100 micrometers. So this is the region of interest to us. 0.4 to 0.7 is critical for sustenance of life it is a visible path. The eyes are capable of detecting radiation only in the 0.4 to 0.7, infrared cameras.

Your night vision cameras which are used by army and all many people, many agencies these can get pictures in the infrared part of the spectrum also. What is h is a Planck's constant it is going to be 6.26 * 10 to the power of - 34 joule second it is the fundamental constant of nature. The whole contribution, the quantum mechanics is that h is finite, h is not 0, h does not tend to 0 that is where the noble prize comes. We will talk about it little latter. Now, classification.

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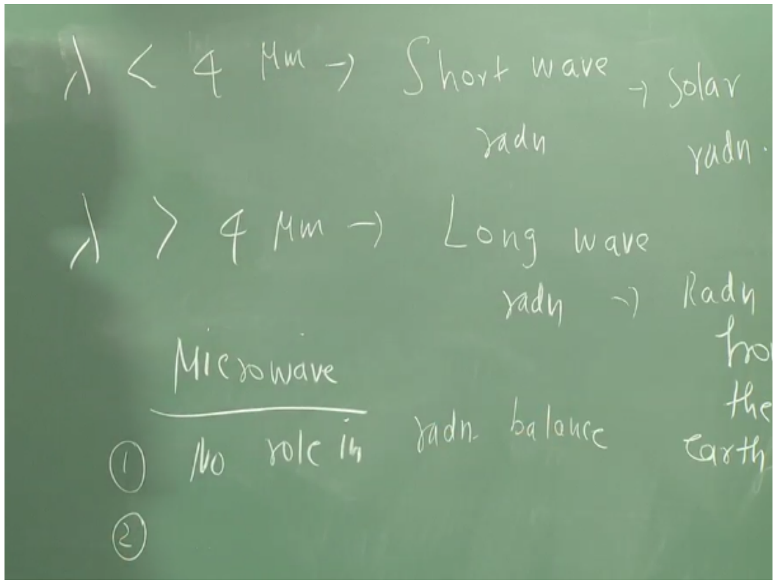

Lambda < 4 micrometer is called short wave radiation. Lambda > 4 micrometer is long wave radiation. So lambda < 4 is here. So the radiation coming on to the earth from the sun, the incoming radiation is it in the short wave or the long wave? Short wave. So solar radiation, but you all know some anyway we learn a little latter through the Wien's displacement law that the earth is radiating only the infrared part of the spectrum, but you already have some background knowledge.

If you know that then you know that the long wave radiation is basically radiation from the earth that is reflected back from the earth. The whole beauty is the conscience of the atmosphere reacts differently to these 2. If they allow the incoming radiation to come through, but they do not allow the outgoing radiation to pass to get to the outside of the atmosphere then there is a buildup of radiation within this.

And there is MCP * dt/d tau = outgoing - incoming or incoming - outgoing there is a build up that leads to global warming and all that we will see this a little later and this effect can be accentuated by burning more fossil fuels, if you have more carbon dioxide then these characteristics will change. These are the Gag gases. So, what about microwave? Microwave has no role in this.

So the earth's energy balance if you look at the radiation budget of the earth the temperature of the earth is determined largely by the incoming radiations from the sun and the outgoing radiation of the earth and how this reflectivity is changed or we call it as albedo, how the reflectivity is changed by the various constituents. Microwave no role, but microwave is very useful in remote sensing how?

Microwave radiations capable of penetrating the clouds. So if you look at the radiations coming from the surface of the earth or from the surface of the ocean if there are clouds and if you keep a microwave sensor on the top of the atmosphere the microwave sensor is capable of picking up the vertical structure of the atmosphere itself whereas if you keep an infrared sensor the infrared sensor will pick up the signature only at the top of the cloud.

If there is no cloud it will go all the way and it will pick up the ocean surface. So it will give you an idea about what immediately obstructs it. So it will give, but if you know the top of the atmosphere temperature through the infrared if you know the laps rate it is possible for you to calculate the height at which this cloud is available and then using your fundas of atmospheric science you can find out whether it is cumulus cloud, this cloud, that cloud, where it will rain.

And so some indirectly you can study atmospheric science using the infrared imagery out. visible is the first thing we came into existence once the satellites are long they put visible cameras and then they were able to take pictures of the clouds and all that and everybody claps and everybody is very happy, but the funda is available only from 6 a.m. to 6 p.m. at night time the visible will not work.

So cyclone will not stop its activity doing okay now I am switching off morning again become active so it is continuously working so this visible has got some even if you look at IMD pictures visible will after 6 o 'clock is gone so only during the day time it will be available. So visible infrared and microwaves use this sounders and images not only to study the cloud pattern and all that actually.

I am doing lot of projects where from these signals we can reconstruct the humidity temperature and the water vapour and the cloud profiling the atmosphere. So this is called passive remote sensing. Microwave remote sensing is offered as a 8000 level course or 7000 level course and atmospheric science disciplines U.S. or U.K. or whatever. So that microwave can be taught for 40 hours.

So microwave remote sensing itself many courses can be taught and remote sensing with respect to civil engineering with respect to topography, with respect to vegetation, and land use that is what civil engineers look at land use patterns where it is dry, where agriculture is this thing, you can look at agriculture productivity and change from satellite pictures. We will look at forest fires using satellite pictures and so on.

So remote sensing is a big thing by itself. Remote sensing can be active or passive. In the case of passive whatever radiation is coming you are just picking up. In the case of active it is like a radar. You send a signal and find out what happens. So there is a radar in Chennai I told you know near the beach so it will send out signals. If there is no rain the signal will go out and nothing will come back. So if the reflected radiation is 0 that means it is clear sky.

Then the strength of the reflected signal will give you the size of the rain drop and this thing and so as the reflectivity keeps on increasing and then if you have a colour patter blue is low reflectivity, red is high reflectivity, yesterday or day before yesterday if you have seen the radar picture around Chennai red, red, red there will be red and orange that means there is heavy rain. So it is very sensitive to rain. It is not sensitive to eyes or clouds it is sensitive to rain drop.

You can decide the frequency normally they take a frequency for example the precipitation radar on the TRMM satellite has got a frequency of 13.8 gigahertz. Around 13 I think Chennai radar is also like that. So remote sensing is a big thing by itself. So the cornerstone remote sensing is radiative transfer. You have to first study radiative transfer and then you have to get down to remote sensing, but now what about the nature of this radiation. Now you will have to do the quantitative description of radiation.

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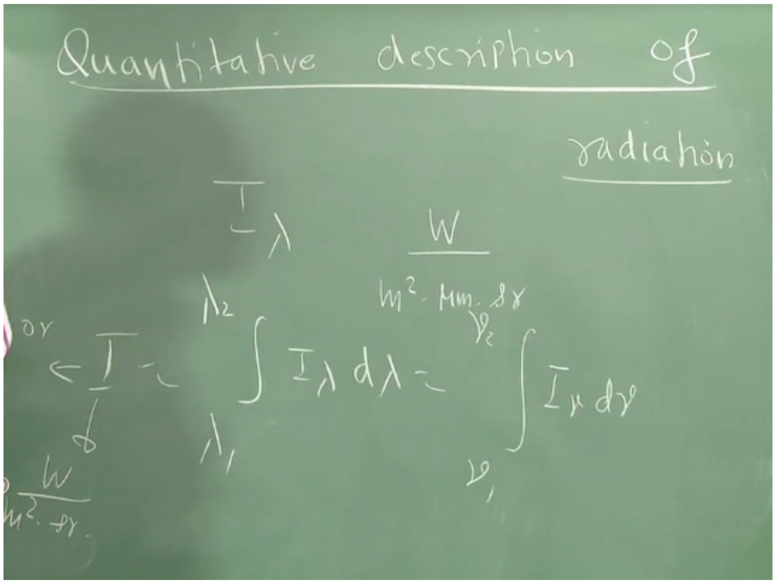

Define a quantity called I lambda which has got the inlets of watts per meter square per micrometer first radiant. Watts per meter square is flux per micrometer is per wavelength difference and steradian is a solid angle. I will explain all of this, but before that please take down the definition of I lambda. The monochromatic intensity is the energy transferred by radiation, the monochromatic intensity or the spectral intensity.

Or the monochromatic radiance, monochromatic intensity or spectral intensity or monochromatic radiance is the energy transferred by radiation in a specific direction passing through unit area normal to this direction per unit time at a specified wave length. Planck actually got this for a black body as a function of lambda and temperature. I lambda, the correct distribution, which won in the noble prize in 1918 for quantum statistics.

We will talk about this a little later may be on Thursday's class. Now I when this I lambda is integrated between 2 wavelength limits lambda 1 and lambda 2 so this is called intensity or radiance. What are the units? This is also equal? It is the same energy contained between lambda 1 and lambda 2, same energy contained between nu1 and nu2 corresponding frequencies or you can do it on wave numbers. Now, physics people would like to work based on I nu, but engineers would like to work based on I lambda. so what is the connection between these 2.

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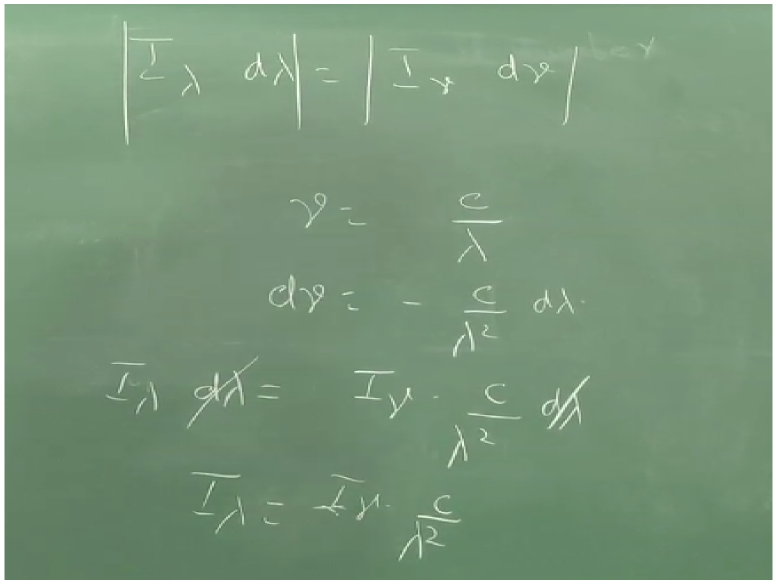

Agreed? If you forget the sign, so I nu is it correct. So I lambda is I nu c/lambda square. Dimension is it okay. Now I had to tell you what this solid angle is.

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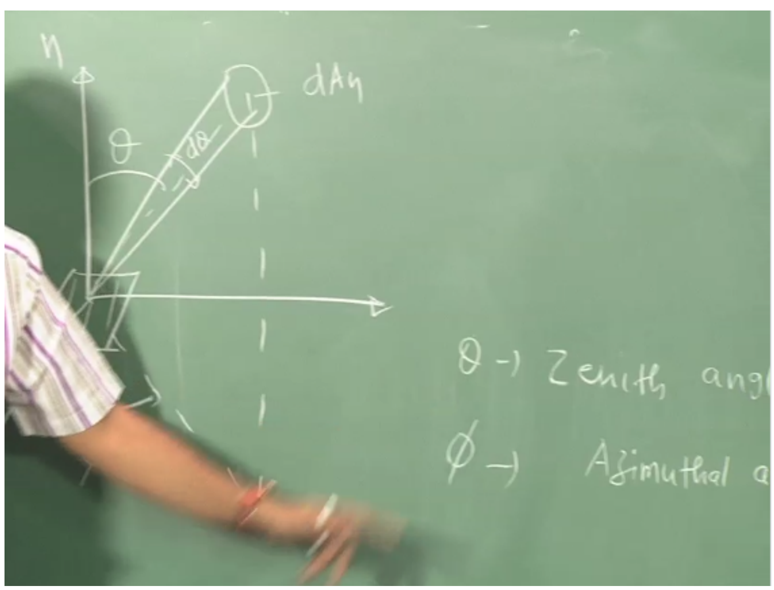

Suppose it is a unit vector. There is an elemental area dA1, dA1 is the emitting surface and dAn is the receiving surface. There is an angle with respect to the vertical which is called theta. This is d theta. If you take a projection of this if it is falling on the xy plane or whatever this angle is called phi. So this theta is called the zenith angle you must have studied in the solar energy and all that and this phi is called the Azimuthal angle.

So what is the radiation which is originating in a particular direction theta phi from an area dA1 which is normal to this direction means you have to take dA cos theta that means cos theta will always combine radiation. So if you take this component will be dA cos theta. So you are finding out what is this stream of radiation which is coming out that is characterized by this I lambda. Then if you want to integrate between a particular theta 1 to theta 2, phi1 to phi2 and lambda 1 to lambda 2 you do the double integration, triple integration.

And so watts per meter square per micrometer plus the radiant is integrate with respect to lambda it will become watts per meter square steradian. IF we integrate to the respect to theta and phi it becomes watts per meter square and then you multiply by the dA1 itself it will finally give you the watts which is an engineering quantity. So from watts per meter square by micrometer steradian we go all the way up to watts.

Sir, already we are comfortable as engineers are comfortable with watts per meter square flux we have so we have used flux so much why should we do this? Very good question, but the answer to that question is watts per meter square, the flux is incapable of handling the theta and phi which are very important in radiation. So the directional nature of the radiation which is spreading in all the 360 degrees which is characterized by 2 important angles called the Zenith angle which is basically the Zenith angle is from here what is this?

So if you look at the corner if you look at this room. So if you are taking about the stream of radiation I am slanting it like this. So this angle is you theta. If I take a projection of this and then it falls like this now you can see you have to believe what is say. Now that shadow is making an angle which is this angle that is your phi. So that phi fully it can be the 360 degrees but Zenith angle is 0 to 90. It will take care of the other one, but we are not talking about the full sphere.

We are talking only about the hemisphere because there is a surface it is receiving only from the other direction if it is bottom then you can consider another hemisphere from this. Usually you do not worry about that unless it is a volume it is a particle of alumina or something which is in a rocket motor aerospace engineer will there is alumina particle burning in a rocket motor and already in those cases we have to consider the full 4pi. So this is the conceptual figure to give you an idea of this radiation streaming in a particular direction.

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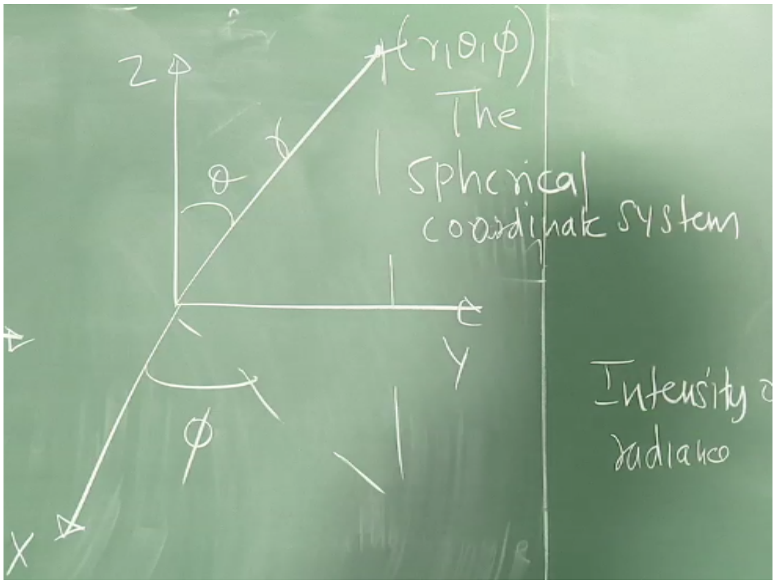

So it is very eminently described by x, y, z, theta. A point here which in the Cartesian coordinate system can be indicated by x, y, z can be indicated this r, theta and phi. So this r, theta, phi is called the spherical coordinate system. It is very useful in the study of radiation. So we will stop here. So we will solve some interesting problem. We calculate I hope to complete the 2 basic laws namely, Stefan Boltzmann and the Wien's displacement law.

I will try to calculate the temperature of the earth, temperature of the sun, and all these the maximum intensity of radiation or solar radiation all these problems in the next class.