Fuels, Refractory and Furnaces

Prof. Dr. S. C. Koria
Department of Materials Science and Engineering
Indian Institute of Technology, Kanpur

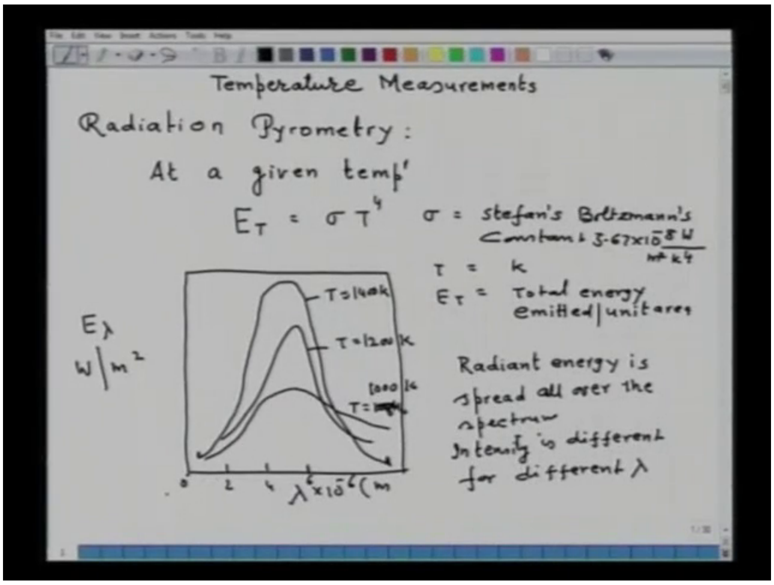
Lecture No. # 37

Miscellaneous Topics: Pyrometry

We will talk today, temperature measurement and this lecture is in continuation of my earlier lecture, where I have said the temperature measurement by thermocouple. And in brief towards the end of the lecture, I have introduced to another method of temperature measurement that is by using the radiation of an object. In very brief introduction over there I have said that the intensity of radiation, it depends upon the temperature of the body, the body at higher temperatures, it emits all wave lengths.

However, the intensity and the wave length, it depends upon the temperature, the total energy intensity of all wave length is given Stefan's Boltzmann's law that is intensity of radiation is propositional to the whole power of absolute temperature that is what I have said. I have also said that, this is non contact type of temperature measurement, thermocouple make a contact with the medium for which the temperature is to be measured. Whereas the in in the Pyrometer, you do not make any contact, so it is a non contact type of temperature measurement. Now, the principle of this, it depends upon the intensity of the radiation, it depends on temperature and wave length, at a given temperature.

(Refer Slide Time: 02:10)



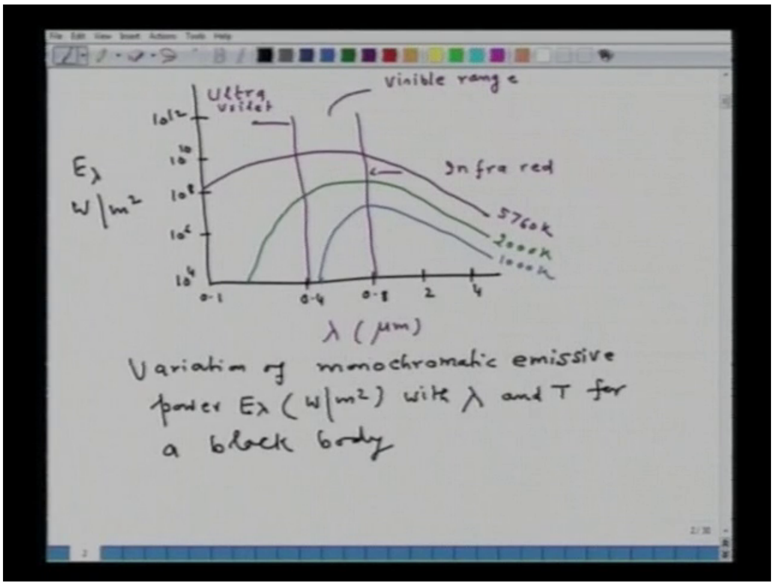
The total energy emitted say, at a given temperature at a given temperature, the total amount of energy radiated by of all wave length of the (()) body given by E T, that is equal to sigma T to the power 4, where sigma is Stefan’s Boltzmann’s constant Stefan’s Boltzmann’s constant. And its value is 5.67 into 10 to the power minus 8 watt watt meter square Kelvin to the power 4 and T, T is in Kelvin where E T is total energy emitted per unit area; I mean this is a famous Stefan’s Boltzmann’s law, and I think you are all aware of it.

Now, if you consider monochromatic wave length, and say we try to make a plot of monochromatic wave length or the intensity of the monochromatic wave length, with the wave length, then the total energy will be the area under that particular term. For example, say if you plot here, if we plot here, E say lambda for example, watt per meter square and we plot against wave length, and wave length let us take lambda into 10 to the power minus 6 in meter, we start from 0, 2, 4, 6 and so on.

So, the the variation it depends on temperature, this is a typical plot of intensity of monochromatic radiation with the wave length for different temperature. So, this is for example, T say let me take approximately equal to 1400 Kelvin, because I have not given any scale on the y axis, so the temperature just represent, take qualitative fashion with reference to, if I take at lower temperature. Let say for example, T that equal to thousand Kelvin, 1000 Kelvin and in between T that is equal to 1200 Kelvin. So, what we see from here, that the radiant energy, what we note from here, that the radiant energy is spread is spread all over the spectrum all over the spectrum. Say for example, if we take curve for T is equal to 1400 degree Kelvin, then you will find the total amount of energy, it is spreading from this particular wave length to this particular wave length (Refer Slide Time: 06:09). Similarly, if you see for 1200 degree Kelvin or 1200 Kelvin temperature, then the radiant energy content, wave length of all intensity, however the intensity is different intensity is different for different lambda for different lambda.

Intensity also depends up on the temperature, so you should note from here, that the energy content with lower wave length, very, very low length 2 or 1 or or say 1 macro meter, it is extremely low, where most of the energy is contain in between the range of the wave length. So, what is important here is to that, the intensity of the wave length is different for different lambda, and also it varies with temperature; the higher is the temperature the intensity of of monochromatic intensity is also higher.

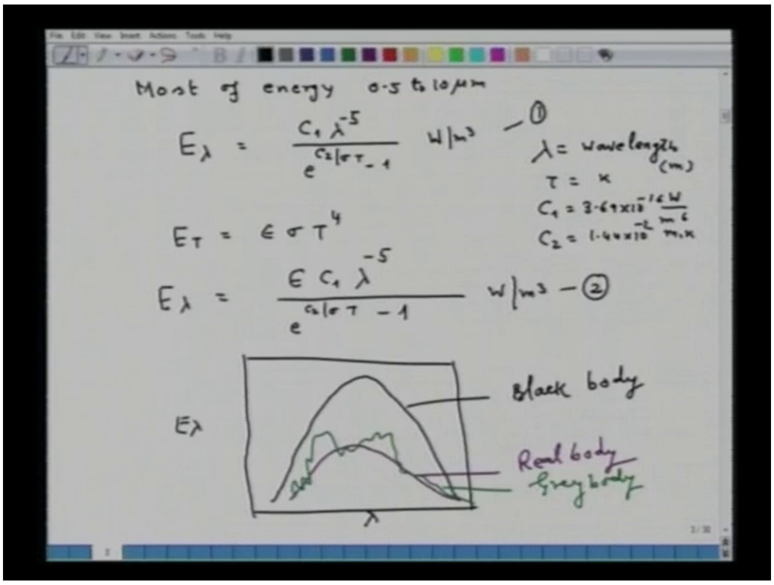
(Refer Slide Time: 07:23)



Now, say if I just enlarge this particular curve, when I try to represent in another fashion, where I superimpose, the region of various wave length say, I will take here 0.1 from here I take 0.4 from here I take 0.8 2 and 4 and here I take E lambda, say let me go from here 10 to the power 4, 10 to the power 6, 8, and 12. So, between 0.4 and 0.8, this is the visible range visible range and from here, it is the infra red range, that is the frequency beyond 0.8 macro meter, it correspond to infra red region, between 0.4 and 0.8, the correspond to visible region. And from here onwards the correspond to the ultraviolet range; then your violet, then x rays, gamma rays, and cosmos rays of very, very lower of wave length. So, here this is the lambda in macro meter, so if you show the variation for example, at very high temperature, say if I plot for very high temperature, then this particular, just I say temperature of very high, 5760 Kelvin; on the other hand, if I take for example, 2000 Kelvin then it has this particular variation, 2000 Kelvin.

Then say for example, if I take 1000 Kelvin then I have the lot of thing (()), this is for 1000 Kelvin. So, what it this is, the variation of monochromatic emissive power of mono chromatic emissive power E lambda in watt per meter square with lambda and temperature for a black body for a black body that is here, watt per meter is there.

(Refer Slide Time: 10:28)



Now, if we analysis this particular curve, we note that most of the energy the most of the energy, it lies between 0.5 to 10 macro meter. Now, the intensity E lambda of a black body that can be given by C 1 lambda to the power of minus 5 upon e c 2 sigma T minus 1 in watt per meter cube, where lambda is the wave length wave length in meter, T is in Kelvin, C 1 is a constant whose value is 3.69 into 10 to the power of minus 16 watt upon meter to the power 6.

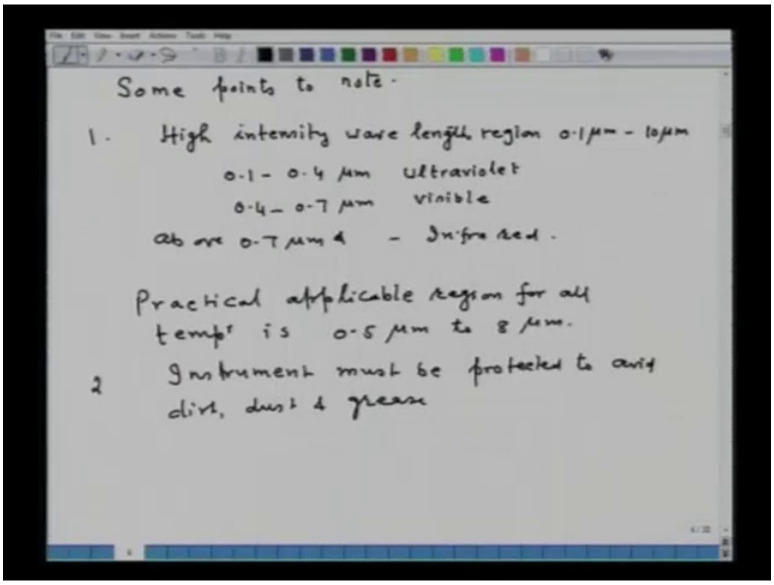
C 2 as a constant, 1.44 into 10 to the power minus 2 meter Kelvin and sigma is again Stefan's Boltzmann's constant. Now, this is the intensity of monochromatic radiation, as function of lambda and temperature, this is perfectly for a black body, but in real we do not we have a sort of real body; and we have to consider for emission from real surfaces by considering a quantity. Emissivity and a search E T total amount of radiation that will depend upon for a real surface, to the power 4 and similarly, E lambda for a real surface belong C 1 lambda to the power of minus 5 upon e c 2 sigma T minus 1 watt per meter cube this is 1, this is equation 2 (Refer Slide Time: 12:31).

Now, if you want to compare the E lambda versus lambda for black and real surfaces, then it looks something like this, I am just showing you symmetric one, this is here E lambda, and this here lambda, so for a black body the variation is something like this (Refer Slide Time: 12:49). This is called black body, were is for real body, this is the case for real body, and for grey body the measurement shows this sort of, this is for the grey body.

So, all that it say that the monochromatic intensity of radiation or in general intensity of radiation is affected by the emissivity of the surfaces; therefore, in order to apply the concept of radiation for temperature measurement, the emissivity of the surfaces is very important. And in this particular contest you see, the emissivity of real body and a grey body is not very different, but however, they are lower than the black body.

So, the radiation pyrometry in fact, it is based on the equation 1 and 2, that means the radiation pyrometry it is based upon the, how how better you can you can see the monochromatic radiation or how better you can you can (()) radiation intensity.

(Refer Slide Time: 14:26)



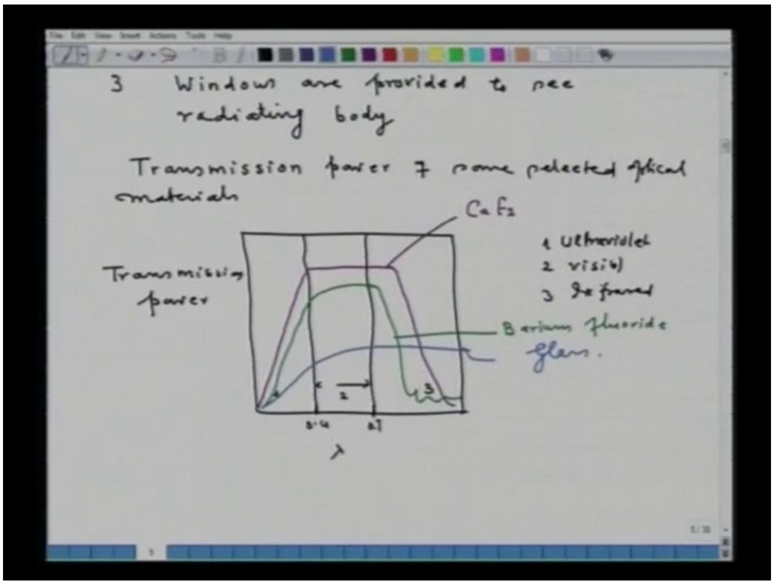
Now, the some points to note some points to note, point number 1, the high intensity high intensity wave length region high intensity wave length region, it lies between 0.1 macro meter to 10 macro meter, what I mean to say that at any temperature, the radiation will be emitted of all wave length. So, that is the important over here, here 0.1 to 0.4 macro meter belongs to ultraviolet, then 0.4 to 0.7 macro meter, that is the visible range; and 0.7 macro meter, above 0.7 macro meter that is the infra red region.

Now, as temperature increases, radiation becomes stronger towards the smaller wave length. Now, the practical applicable region practical applicable region practical applicable region for all temperature for all temperature is in between 0.5 macro meter to 8 macro meter, which correspond to visible, as well as infrared range region. Second important thing is to note, since we are going to measure the temperature by radiation that means we will be comparing the radiation emitted, by the object with some standard intensity of radiation.

So, it is obviously most important, that the part of the radiation should not be dirt by dust by dust, by gases and so on; second important point, the instrument which are going to be build up, say instrument it must be protected it must be protected to avoid dirt, dust and grease, they are present which are present in the environment. Because, ultimately the radiations of a body of which the temperature is to be measure, we will be seen those radiations through a window, that means (()) to provide a window; so that we can see, the radiation eminated by the body.

So, for that purpose, anything is comes in between the the radiation and window, the some amount of radiation will be loss, and will not be able to measure the correct temperature. Another important thing is that, the material of the window, you are seeing through the window, and the window should have a very high transmissivity, that means it should be able to transmit all radiation of all wave length to your eye for comparison purpose.

(Refer Slide Time: 18:50)



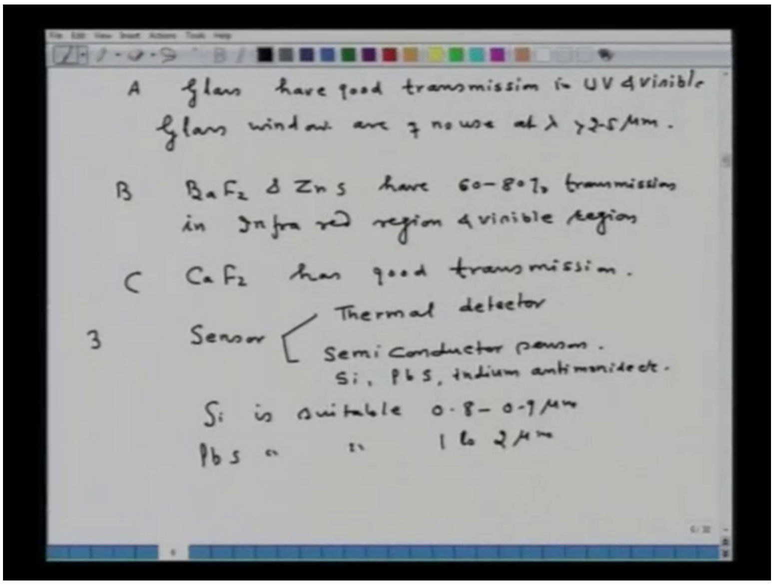
So, again important, third important thing over here, third thing the windows are provided windows are provided to see the radiating body to see the radiating body and here the transmissivity of the material of the window body is important. Say for example, all all optical materials have their own transmissivity that is they allow only particular wave length to pass through sufficient intensity, and for most for some of the wave length they are opaque.

So, it is important, they should have selected an optical material, which transmits most of the wave length, which is coming from a body for comprising purpose. So, here for example, if I say transmission, transmission power transmission power of some selected optical materials can be shown, say if I plot here, they are very different type of optical materials is available.

So, here take the wave length region 0.4, 0.7 this is the visible range, and here I take transmission power, I take here transmission power or transmissivity and here the lambda, so for example, if I take and this region is this is this is the say one, two and three, one ultraviolet, second visible and third infra red. So, we say for example, the calcium fluoride if we use in optical material, then the calcium fluoride, it has a sort of behaviour for transmissivity.

So, this curve is called, when calcium fluoride is used as window material for example, if you used the barium fluoride, then the barium fluorides say this one; and this is for barium fluoride. And if I take glass which is popularly available, then glass as a sort of air, so what we note from here, the following points.

(Refer Slide Time: 22:12)

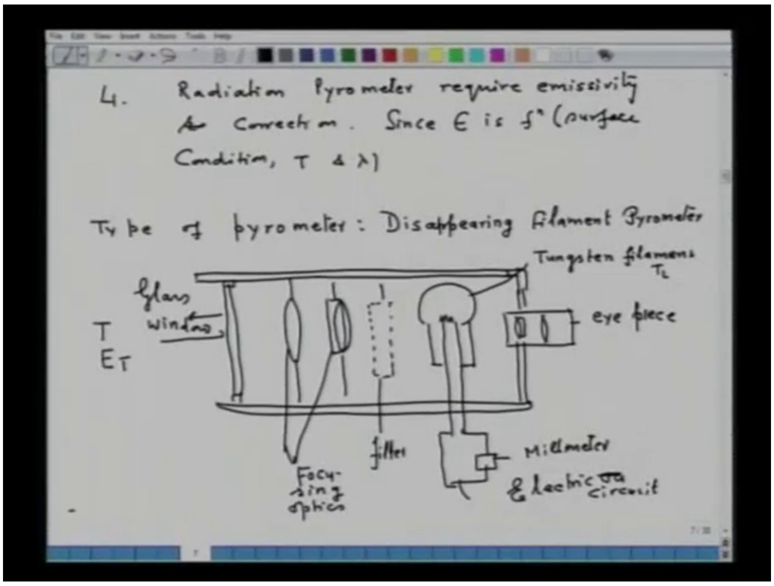


Point number A, say glass for that metal called term glass or pyrex, have good transmit have good transmission have good transmission in ultraviolet and visible region and visible region but, they are opaque to infrared, since we are seeing the infrared site, it is just increasing. So, the glass windows glass windows are of no use at lambda greater than 2.5 macro meter. Similarly, B, point number B is that, say barium fluoride and for example, zinc sulfide they have 60 to 80 percent transmission in infrared region and visible region and visible region. And see, the calcium fluoride has over all good transmission.

So, the selection of the material of the window is important, in order to measure that temperature of the object correctly, because the most important point is direction of the material of the window, that is to be able to transmit, most wave length for comparison purposes. Now, third important thing is that, the radiation parameter will required a sensor; a sensor which can detect the incident radiation, and generate an electrical signal. So, one does required a sensor which sense so called the incident radiation, and it can create an electrical signal.

Now, here sensors thermal detectors are used, thermal detectors can be use the sensors, which are consists of different types of thermocouple elements, wires. And second the semi conductor sensor semi conductor sensors and the semi conductor sensors are based upon use of silicon, lead sulphide, indium anti indium anti monide etc. Now, the response of the semi conductor sensor is simultaneous compare to thermal sensor, but it selective to particular wave length. For example, silicon is suitable for 0.8 to 0.9 macro meter wave length, now this can be co-related to the temperature similarly, lead sulphide is suitable, 1, 2 to macro meter, so that is an important thing.

(Refer Slide Time: 26:19)



Fourth important thing is that, radiation pyrometer should be kept away from the dust partials, because they will scatted the radiation, any material or any gases which can be scatted the radiation, that will effected the temperature measurement. Therefore, the radiation pyrometer should be way from all these gases or dust partials, which can be scatted the radiation. Also the radiation pyrometer radiation pyrometer, require emissivity correction require emissivity correction.

Now since, the emissivity epsilon is a function of surface condition, this is the basic which all of you know, surface condition, temperature and wave length; therefore, the (()) during the measurement. For example, you are using the (()) and if it oxidized, then when it does not oxidized, then then the emissivity correction has to be applied, in order to make a correct temperature.

Now, there are several types of radiation pyrometer are build based on the concept. Now, if I summarized, then the conceptive part of the radiation pyrometer, then I can summarized as follows. Essentially you need a sensor a sensor should able to detect a incident radiation, and these incident radiation after deducting by the sensor it creates a electrical signal of course, these that sensor should also give an electrical signal, so that temperature can be measure.

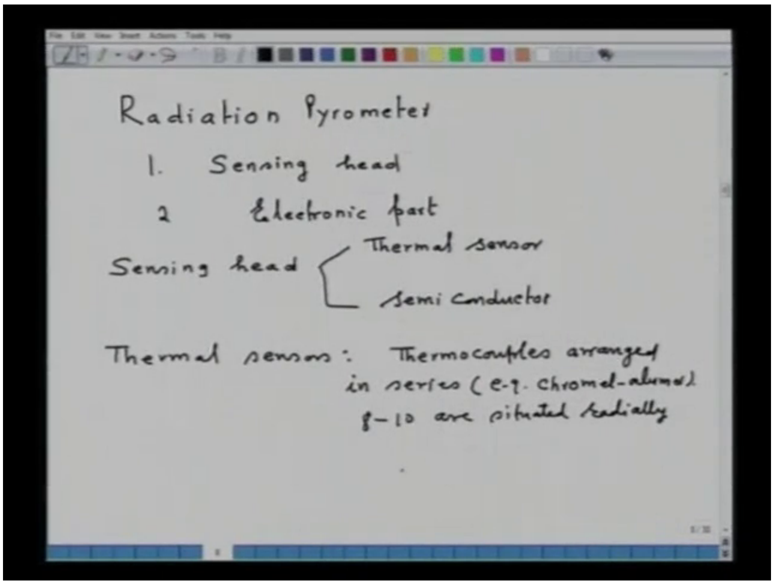
So, based on this, we have one type of pyrometer type of pyrometer say one is the disappearing filament pyrometer disappearing filament pyrometer; now when you think of pyrometer it should have all say different arrangement of lens, mirrors, so that it can direct the beam to the sensor. So, a disappearing filament type of parameter, it looks something this way. So, this is the pyrometer body, this is the so called pyrometer body, and here we have a glass window. So, this is a glass window, which is seeing the radiation at temperature T and the intensity of radiation of all wave length that is E T.

Now, see we further required the so called focusing of pix, that focus the beam, so these are the, this one and this one, they are the focusing optics focusing optics, because the the radiation coming out to focus the beam, naturally one does required a sort of filter (Refer Slide Time: 30:20). So, this is a filter, this one is a filter, the filter all unnecessary type of things, and then you have a sort of a a, so this I put as a filter, then you have a tungsten filament, that is store with which the intensity of radiation will be compare.

So, this is a filament this is the filament and say this one is a tungsten tungsten filament which is for example, take some temperature T L, that the material. Now, you do require something to see and there we have the eye piece, there we have eye piece and it again has a sensor and mirror, for focusing purposes, so this is the eye piece (Refer Slide Time: 31:45). And here say, we have the this I am not showing, it is simply the millimeter which is calibrate in degree celsius, and this is the electric circuit this is the electric circuit to change the intensity of the tungsten filament, depending upon the intensity of the radiation emitted by the body.

So, this is in fact very simple construction of disappearing filament pyrometer. Now, you see the radiation is emitted from a body, radiation called this way, the objective of the focusing optic is direct the beam, and unnecessary thing are I mean filter out. And intensity of the beam is match by the intensity of the tungsten filament, and whose intensity is adjust by an electrical circuit; so that, when the both the intensity are match then a (()) is obtain on the millimeter which you can get (()) in terms of (()) also or that millimeter can be calibrated in terms of temperature.

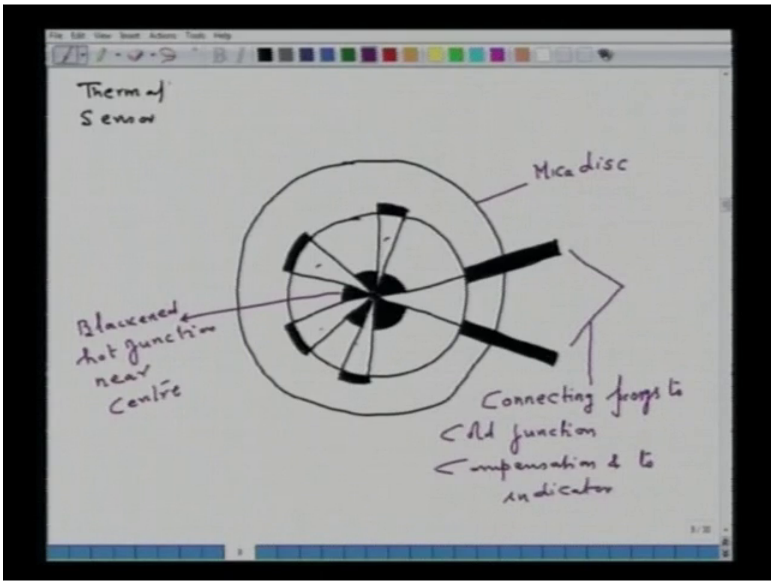
(Refer Slide Time: 34:10)



So, that is what the function of the disappearing filament type of pyrometer, now another type of pyrometer that is the radiation pyrometer radiation pyrometer another type of pyrometer that is the radiation pyrometer, now the radiation pyrometer it also has, one sensing head sensing head or you can also called if you detected, that means it will detected the intensity of radiation. And then mass is the sensing head, and second you have electronic part, and the electronic part the adjust to compare the intensity of the radiation of the object.

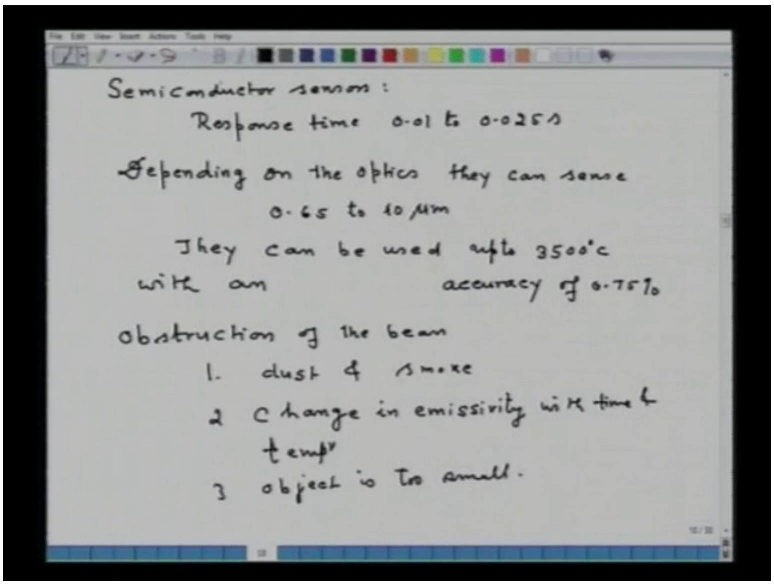
So, the sensing head the sensing head it is or there are thermal sensor or they are semi conductors they are semi conductors. Let us see while thermal sensors is, now in fact thermal sensor thermal sensors were the consists of several thermocouples thermocouples, they are arranged in series arranged in series; where thermocouple would be for example, chromel, alumel for example, chromel, alumel normally 8 to 10, they are situated radially and connected in series.

(Refer Slide Time: 36:47)



So, this is the semantic presentation of the thermal sensor, this one say this is a mica disc mica disc and these two they are say connecting frongs connecting frongs to cold junction compensation cold junction compensation and to indicator. These things are that one is the blackened hot junction near center, and these are the thermocouples. So, that is the how the thermal sensor looks, and the thermocouples they are arranged in series for temperature measurement.

(Refer Slide Time: 38:15)



Another sensor is the semi conductor sensors semi conductor sensors, they have a response time response time is very short around 0.1 to 0.05 seconds however, the thermal sensor may have a little a longer response time, were semi conductor sensor may be very small response time, because of their electronic sensitivity.

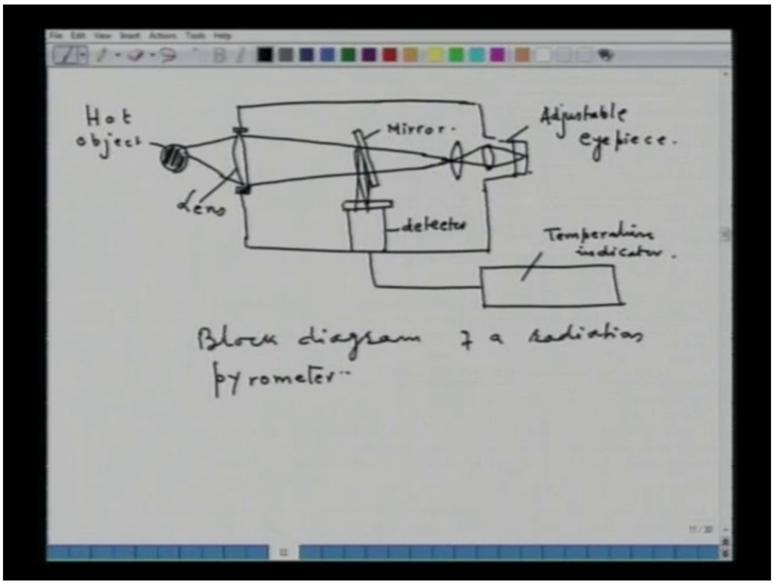
Now, depending on the optics say depending on the optics which is used to see the radiation, they can since of the semi conductor sensor and since, 0.65 to 10 macro meter wave length intensity of radiation between, this ranges they can since intensity of radiation. They can be used they can be used up to 3500 degree celsius with an accuracy of with an accuracy of 0.75 percent full estate.

Now, the sensors, they may be sensing a very narrow very narrow wave length, then or a ford wave length that depend on the type of sensor. Which is under used, normally one can say that a radiation pyrometer based on the semiconductor sensing device, they can go for the very high temperature, they will be accurate as compare to thermal sense. However, it depends on the other factors also, the type of window material, and the environment, the whether the radiation are scatted or not, all these things affects the accuracy of the measurement of temperature by radiation pyrometry.

Now, obstruction of the beam obstruction of the beam, I mean say radiation beam, it can cause incorrect measurement temperature radiation, as I have said that the radiation intensity which is emitted by an object; it should not be ended by any dust, dirt or the gases which can be scatted the radiation, and they all lead to incorrect measurement. And this obstruction of the beam may be may be due to present of dust and smoke, other important thing is the change in emissivity change in emissivity with time and temperature.

Because the surface is, surface electricity might have been change is important (()), third the object is too small object is too small, now a radiation pyrometer, it will look something can be shown semantically wireless.

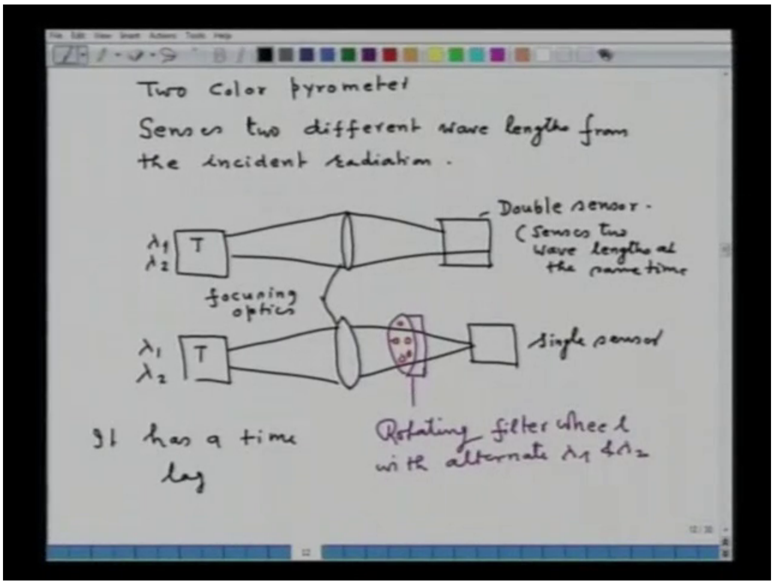
(Refer Slide Time: 42:44)



This is a sort of lens, this is a lens, this is a hot object put it and it is emanating radiation, and then we have a sort of a mirror, this is a mirror and the passing through the mirror, then again there are lens collect this thing. So, this is how this one here, one, so this is let me entices the hot object, this is the hot object, this is the lens, this is the mirror, and this one is the adjustable eye piece adjustable eye piece.

And from here (No audio from: 44:48 to 45:00) this one is the so called detector, that is the beam to mirror is directed, I mean when this detector, it detects the intensity of radiation and from here it goes to this is the temperature indicator. And this is the block diagram block diagram of a radiation pyrometer a radiation pyrometer.

(Refer Slide Time: 45:58)



Now, in this also there are two colour pyrometer are also in use two color pyrometer are also in use, and these two colour pyrometer, it senses two different wave length it senses two different wave lengths from the incident radiation incident radiation. Now, this is achieved by two separate detectors or we take a rotating disc filter that is either we take two separate detectors, each for one for different wave length and another for a different wave length or we take rotating filter, and according to the wave length we adjust the rotating filter.

So, it is for example, we have an object which is emanating the radiation at temperature T wave length lambda 1 and wave length lambda 2, column on a mirror sorry on lens and this one we have the so called, this is the double sensor. And these double sensor, it senses two wave lengths at the same time two wave lengths at the same time, this is some sort of what you call, say detector which can sense two different wave length at same time.

Another way we have, a rotating filter, again have an object here which is a temperature T, emanating radiation lambda 1 and lambda 2, it goes to the focusing optics, so we say this one and this one, they are the focusing optics focusing optics (Refer Slide Time: 48:35). And here, it goes to a single sensor a single sensor and some were here, we have rotating filter wheel, look something this way (No audio from 49:08 to 49:20) this is a rotating filter wheel rotating filter wheel with alternate lambda 1 and lambda 2, and it has it has so called the area. Now, if you use this rotating filter, now if you want to compare these two type of mechanism or two type of instrument we can, which are use under the two colour pyrometer, then you can see that in double sensor, the time wave length is very very small, as compare to. In case of rotating filter wheel, the it has a time lag, it has a time lag, because to adjust the wheel for sensing the wave length, whereas incase of double sensor, we do not have the so called this type of time lag.

So, this in short what I tried to give you an over idea, in this lecture as well as in previous lecture, the various method of temperature measurement to summarized in one, we use the thermocouples which is based on the use of two different materials, when they are joined, they produced an electromotive force; this is one mechanism. This is a principle mechanism on the on that bases several types of different materials we have been searched, and several types of thermocouples are made.

Another one is the pyrometer, which is based on the measurement of intensity of radiation or precisely we can say which is based on the comparison of the intensity of radiation emanated by the object with the standard radiation, and thus we get temperature. Thermocouple is contextual device, I mean it contacts the medium whereas the radiation pyrometer, it does not have any contact it is a non contact type of temperature measurement. So, depending on the situation, one can use thermocouple as well as radiation pyrometer, for distant measurement may be thermocouple may be the radiation pyrometers are good; so I try to give you a brief about the temperature measurement.