Experimental Methods in Fluid Mechanics

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Lecture 26 - Temperature measurement by radiation, the optical pyrometer

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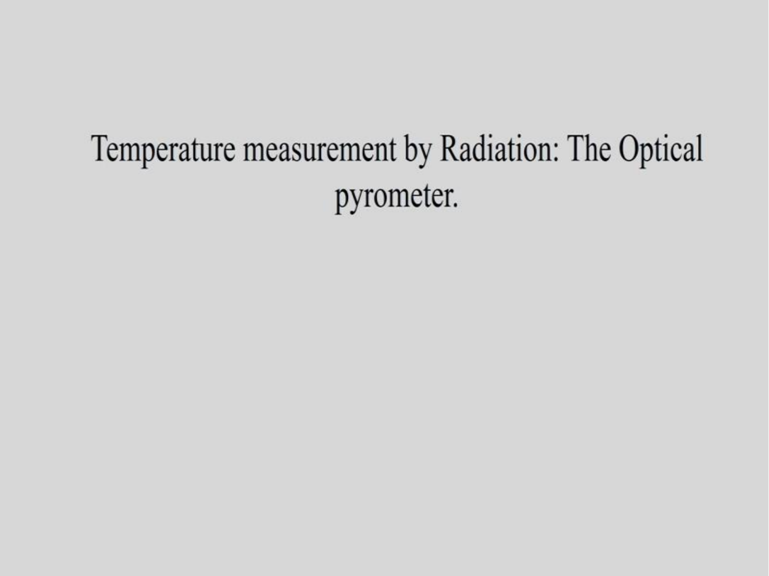

Temperature measurement by Radiation: The Optical pyrometer.

Good morning! We will continue our discussion on Experimental Methods in Fluid Mechanics and today, we will try to discuss about another module that is the measurement of temperature using optical pyrometer. In fact, to discuss the principle of measuring temperature using optical pyrometer, we need to know that the effect of radiation can also be employed to measure the temperature. And today, we will discuss that if you would like to exploit the effect of radiation to measure the temperature, then what is, what will be the measurement technique, measurement principle and then we will finally try to know the limitation of this particular method to measure the temperature.

So, to start with, if we try to recall that we have studied in our undergraduate heat transfer course, that the radiative heat transfer, which is of course, the radiative heat transfer from blackbody, which can be given by functional relationship and which is essentially temperature. Then, from that the radiative heat transfer, that energy can be distributed over a radius and spectrum.

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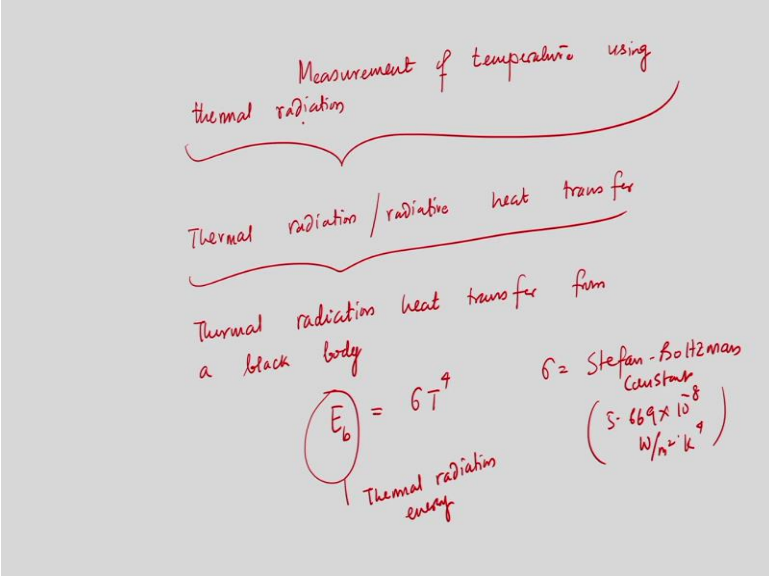

Measurement of temperature using thermal radiation

Thermal radiation / radiative heat transfer

Thermal radiation heat transfer from a black body

$\boxed{E_b} = \sigma T^4$

Thermal radiation energy

σ = Stefan-Boltzmann constant

$(5.669 \times 10^{-8}\ W/m^2 K^4)$

So, if we now try to recall that the radiation, radiative or radiation, so today, we will discuss about the measurement of temperature using thermal radiation. Now, the thermal radiation heat transfer, thermal radiation or radiative heat transfer, which is important to know. And the thermal radiation heat transfer for a blackbody can be expressed by a functional relationship and the amount of radiative energy which is the explicit function of the temperature.

So, the thermal from a blackbody can be expressed E b is sigma T power 4 that is what we have studied in our undergraduate heat transfer course. Now, where sigma is Boltzmann constant, Stefan Boltzmann constant, a numerical value is that we know 5.669 into 10 power minus 8 watt per meter square Kelvin 4. Now, this is the, E b is the amount of thermal radiation heat transfer, which is from the, for a blackbody and which is a function of temperature that is what we can see from the, from this relationship. Now, this energy, this E b. So, this is the thermal energy, thermal radiation energy, that energy will be distributed over a radiation spectrum and that is we also have studied in our undergraduate heat transfer course.

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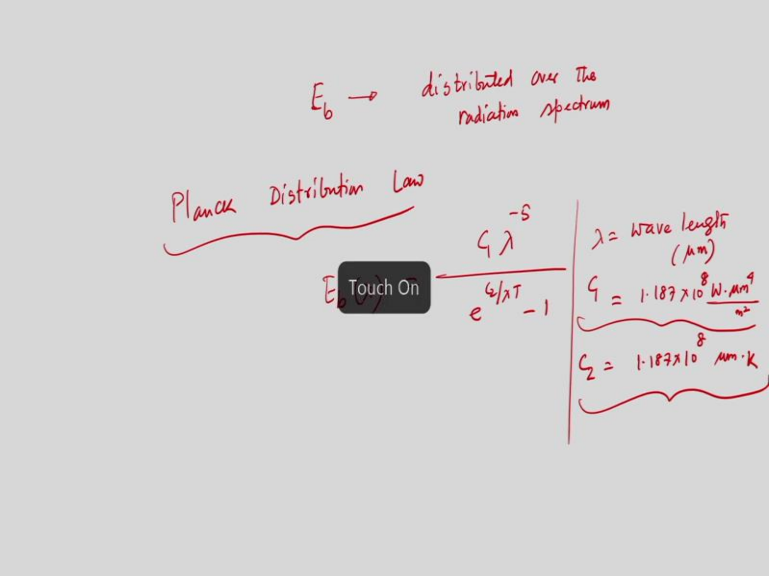

$E_b \rightarrow$ distributed over the radiation spectrum

Planck Distribution Law

$$E_b(\lambda) = \frac{C_1 \lambda^{-5}}{e^{C_2/\lambda T} - 1}$$

λ = wave length (μm)

$C_1 = 1.187 \times 10^{8} \frac{W \cdot \mu m^4}{m^2}$

$C_2 = 1.187 \times 10^{8} \mu m \cdot K$

So, that means this energy E b which is distributed, so I am writing this is distributed. So, this E b over the radiation spectrum and the spectrum which is governed by the Planck’s distribution law. So, now, that is what we have studied that Planck's distribution law, which describes the radiation energy which we are getting, thermal radiation energy for a blackbody and that energy will be distributed over radiation spectrum. And that is obtained by this distribution law that is nothing but C1 lambda power minus 5 divided by E power C2 by lambda T minus 1.

So, this is again C1 and C2 are constant, C1 lambda is the wavelength, we have, we know all these parameters, we have studied these, but again I am writing lambda is the wavelength, C1 this wavelength in micron, C1 is constant and that is 1.187 into 10 power 8 watt micrometre to the power 4 divided by meter square and C2 is another constant that is 1.187 into 10 power 8 micrometre degree Kelvin. So, these two constants and lambda is the wavelength.

Now, question is, if we try to plot this distribution, that is the radiation, thermal radiation energy, which is coming from a blackbody and that is distributed over the radiation spectrum, and that spectrum is, I mean that radiation spectrum, I mean the wavelength of that spectrum is governed by the Planck distribution law. Now, if we try to plot this for two different temperature, we will see insides and from that, we will see how we can use this expression to measure the temperature.

Of course, there is a limitation that this, if you would like to use this mechanism, this technique to measure temperature, then the temperature of the object, temperature of any point that we would like to measure would have I mean, that is very important, I can say point that will produce a visible light. So, that means, if we are interested in the temperature of a particular object, or of a particular point, that particular point or I mean the temperature of that particular object or point will produce a visible light and that is the limitation of this particular technique that I will discuss again.

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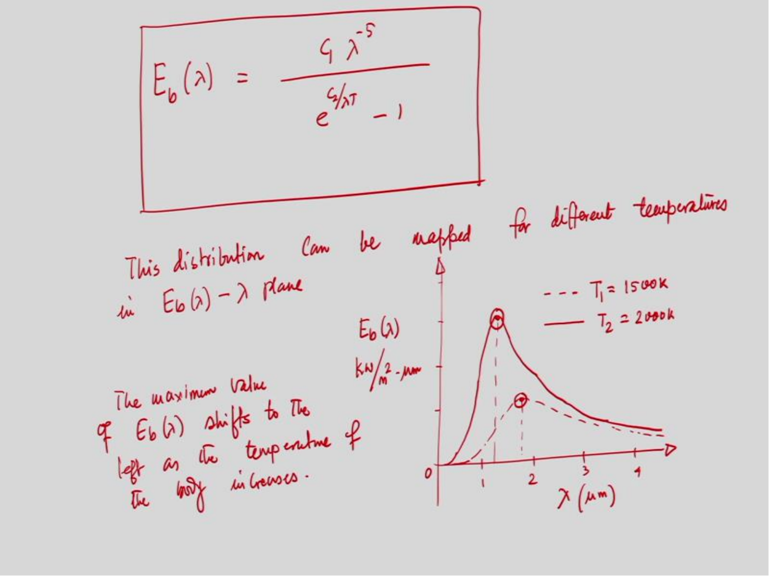
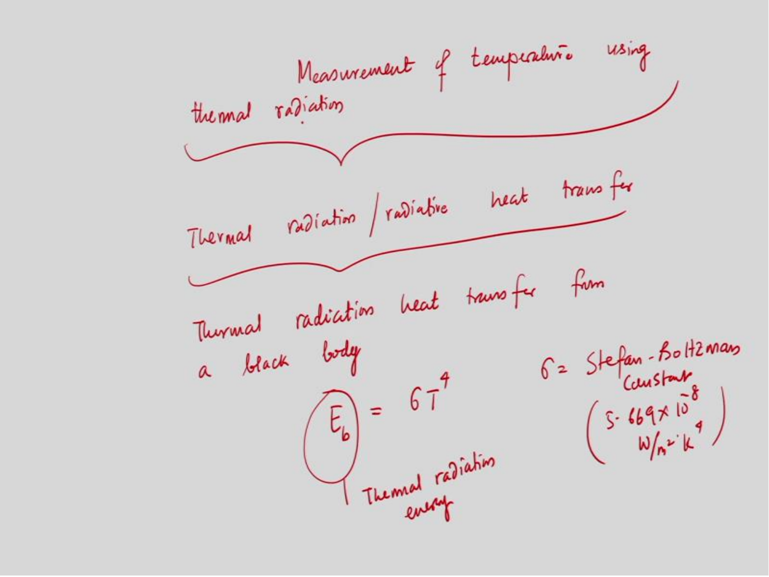


$$\boxed{E_b(\lambda) = \frac{C_1 \lambda^{-5}}{e^{C_2/\lambda T} - 1}}$$

This distribution can be mapped for different temperatures in $E_b(\lambda) - \lambda$ plane

The maximum value of $E_b(\lambda)$ shifts to the left as the temperature of the body increases.



$$\underbrace{\text{Measurement of temperature using thermal radiation}}$$

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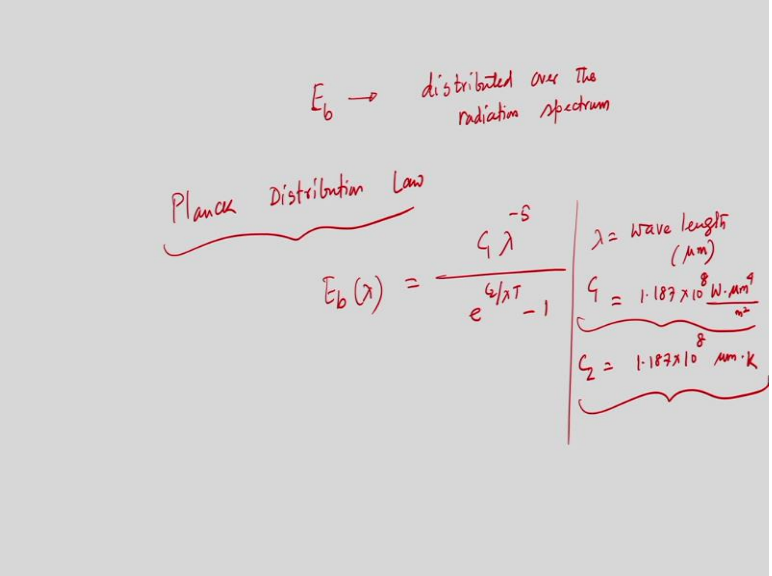
Thermal radiation heat transfer from a black body

$$E_b = \sigma T^4$$

Thermal radiation energy

σ = Stefan-Boltzman constant $\left(5.669 \times 10^{-8}\ W/m^2 \cdot K^4\right)$



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$C_2 = 1.187 \times 10^{8} \ \mu m \cdot K$

Now, if we try to plot that means E b lambda that is what we have seen that is nothing but the C1 lambda power to the power minus 5 divided by. So, that means, E b lambda that is C1 lambda power minus 5 divided by C2 into e power sorry, e power C2 by lambda T minus 1. So, if we plot this, if we plot this that means this distribution can be mapped for not only two for different temperatures.

So, if we now try to plot say we are, this is E b lambda and this is lambda which is of the, which is micron and this is E b that is kilo watt per meter square micron. So, if we try to plot, rather if we try to obtain the distribution using the expression, which is written above for two different temperatures, the distribution can be mapped for different temperatures that it could be mapped in E b lambda plane, in E b which is function of lambda and lambda plane.

So, if we try to, so, this is 0 and we will have 500 say this value and 1, 2, 3, 4 like this. So, we will see that and so, this is for temperature, say temperature T1, this dashed line for temperature T1 is equal to 1500 Kelvin. If we use another temperature and now try to plot or try to find the distribution of E b lambda and in this plane then we will get a profile like this. So, this firm line is for T2 which is say 2000 Kelvin. And these are the, if I that means, this is the plots, which we have mapped in E b lambda, lambda plane obtained for two different temperatures, T1 and T2 which are 1500 and 2000 Kelvin.

What we can see from this plot is that, which is very important, what we can see that the maximum value of E b lambda shifts to the left, as the temperature of the body increases. That means, if we increase the temperature of the body, the body will, from the body we will get thermal energy distribution and that distribution that is what we have discussed in the last slide, that this distribution can be expressed like this sigma T power 4 and the energy, the thermal energy which you are getting that will be distributed over the radiation spectrum and that is governed by the Planck distribution law.

And we have now tried to map that radiation energy, which is now distributed over the wavelength, over the spectrum and this distribution is mapped into E b lambda, lambda plane, what we did? We have tried to obtain the distribution for two different temperatures, that is T1 and T2 the I mean the distribution can be mapped for different temperatures of course, but see this, but what we can see the peak value of E b lambda that is the peak or the maximum value of the thermal energy, radiation energy which shifts towards the left as the temperature of the object increases.

And if we somehow can predict the shift of this maximum value of E b lambda from and this technique now we can use what will be the temperature. That means, by knowing this shift of E b lambda, we can say the rise in temperature is by this amount. So, this shift which plays an important role to predict the temperature of the object and that is what we will see now.

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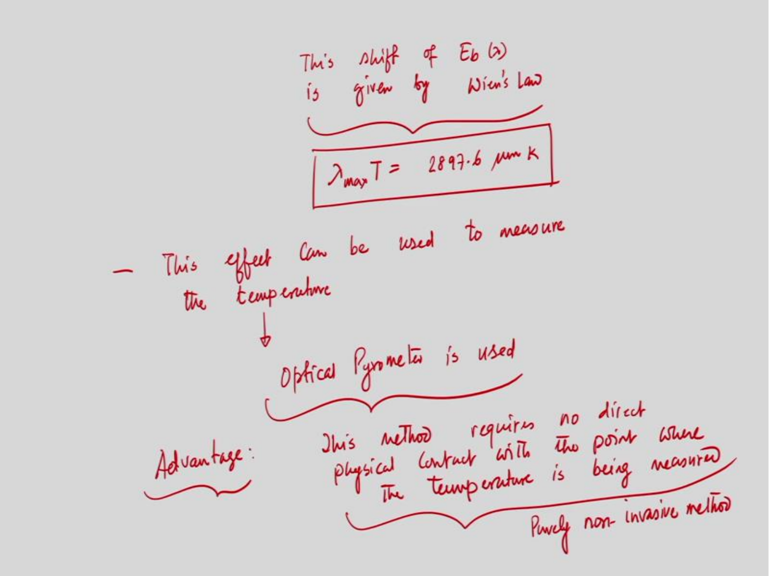

This shift of $E_b(\lambda)$ is given by Wien's Law

$$\boxed{\lambda_{max} T = 2897.6\ \mu m\ K}$$

- This effect can be used to measure the temperature

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Optical Pyrometer is used

Advantage: This method requires no direct physical contact with the point where the temperature is being measured

Purely non-invasive method

So, the body increases and the shift in, the shift of E b lambda is given by Wien's law, what is that? That lambda max into T that is 5215.6 micron sorry, this is 2897.6 micron Kelvin. So, now, that means, by knowing this shift, we can obtain the rise in temperature of the object and that is what is the principle by which we can measure temperature of a particular object using thermal radiation. So, this is the technique, this is the I can say, theory behind measuring the temperature of a, of an object using the radiation effect. So, that means this effect I am writing, this effect can be used to measure the temperature.

If we now try to understand the, you know this technique, then we will find that this is the method by which we can measure temperature without having direct contact to the point where the temperature is being measured. That means, this is the technique using which we can measure temperature without having direct contact to the point where the temperature is being measured. So, this is very, I can say, a non-invasive technique of measuring temperature.

So, this is the advantage and this effect can be used to measure the temperature and the, this effect, I mean to exploit this method to measure the temperature, optical pyrometer is used, optical pyrometer is used. So, the optical pyrometer is used to exploit this effect to measure the temperature. Merit of this method is that I am writing advantage this method, rather I can write excludes or I can write this method requires no direct contract, no direct I can say physical contact with the point where the temperature is being measured.

That means and that is why this method is known as purely non-invasive method in measuring temperature that means, we do not, we measure temperature using thermometer, we have seen, we measure temperature using hot, you know or anemometer I mean sorry, we measure temperature using we have seen yesterday that is thermocouple. But in all these cases, we need to go for the invasive method that means, we need to go for the direct contact, but this is the method which requires no direct physical contact with the point where the temperature is being measured. And that is why it is known as the purely non-invasive method. So, optical pyrometer is used to measure the temperature.

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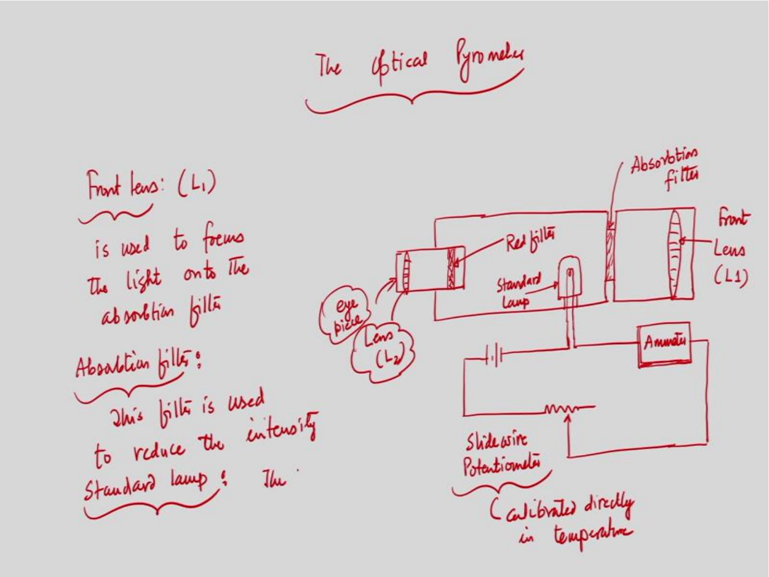

The Optical Pyrometer

Front lens: (L_1)

is used to focus the light onto the absorption filter

Absorption filter:

This filter is used to reduce the intensity

Standard lamp: The

Now, we will try to see the operational principle of the optical pyrometer. So, an optical pyrometer which is used to measure the temperature using this radiation effect. So, to understand the I mean, we have seen the theory behind it, but at least we should know now the measurement technique, if we use optical pyrometer this instrument, what are the different parts of this instrument and their functions and also, we need to know if we really use this in real-time application. Then, at least we should know the physical safe and different components and as I said the different parts and to know that we need to know the schematic depiction.

So at least I will try to sketch the optical pyrometer schematically and we will try to know what are the different parts therein and their different functions. So, optical pyrometer, so, this is a schematic depiction now, I will try to level different parts. So, this is the font lens, so this is lens L1, this is known as absorption filter, filter, this is ammeter and this is standard lamp, this is standard lamp, this part is known as red filter and this is lens L2 of course, and finally this is known as eyepiece. And this is slide wire potentiometer which is calibrated directly in temperature.

So, this is the schematic depiction of the optical pyrometer. What we can see, there is one lens which is known as front lens. So, the front lens is there, then we have absorption filter and the different other parts and ultimately, before in the eyepiece we have another lens that is L2. So, now if we try to write the objective, so front lens, the front lens L1, the function is used to focus the light onto the absorption filter. As I said, that this method can be used only to measure the temperature of a particular point or object if that object or point produces a visible light.

So, when the light is coming, that light will be taken to the front lens first and that front lens is used to focus the light, the incoming light which is coming from that particular point or object where the temperature is measured rather where we would like to measure the temperature that lens now focuses the light onto the absorption filter. So, this is the objective of the front lens. Then it is coming absorption filter, what is the function of this? This filter is used to reduce the intensity. So, the filter is used to reduce the intensity of the light which is coming from any particular object or point and then we are having standard lamp.

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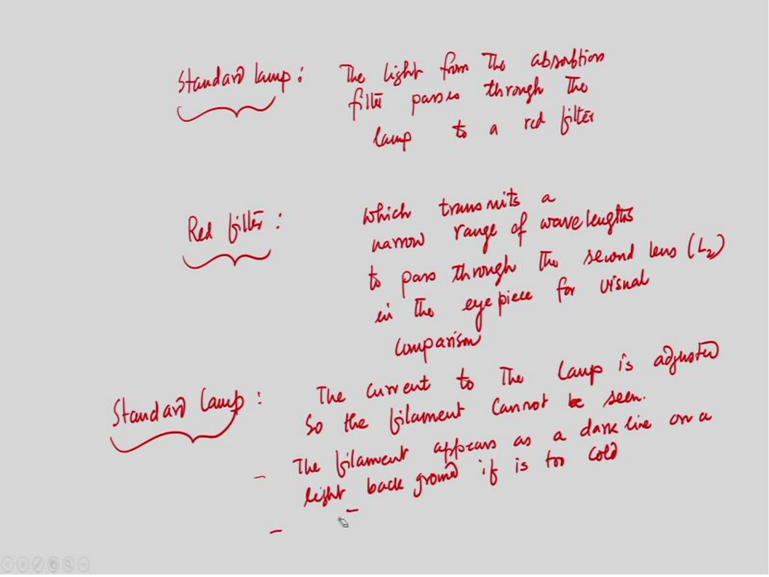

Standard lamp: The light from the absorption filter passes through the lamp to a red filter

Red filter: which transmits a narrow range of wavelengths to pass through the second lens (L_2) in the eye piece for visual comparison

Standard lamp: The current to the lamp is adjusted so the filament cannot be seen.

- The filament appears as a dark line on a light background if is too cold
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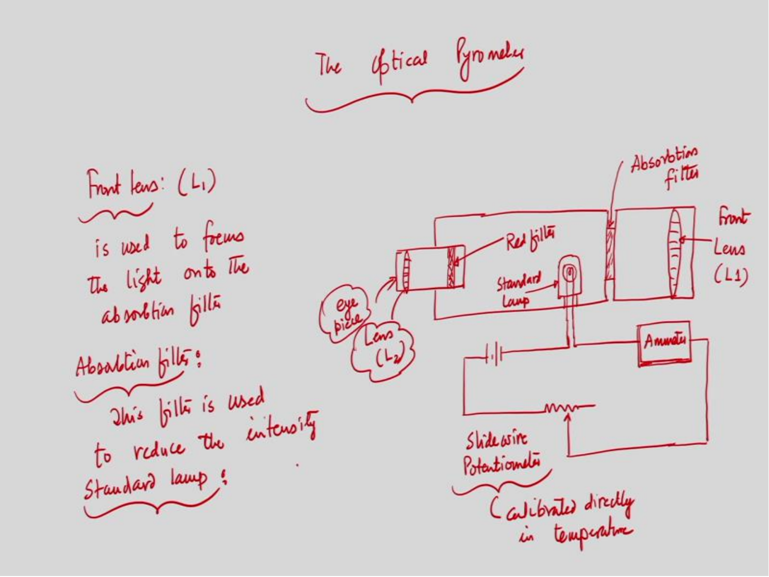

The Optical Pyrometer

Front lens: (L_1) is used to focus the light onto the absorption filter

Absorption filter: This filter is used to reduce the intensity

Standard lamp:

So, next, we have standard lamp, what is the function? That means the light, so, I am writing in the next page that the standard lamp. So, the function is the light from the absorption filter passes through the lamp to a red filter. Now that means the light, the standard lamp which is kept intentionally, and if we try to look at the schematic carefully, we can find the lamp is now connected with another circuit where the potentiometer location is varied and the current which is adjusted to the lamp and we can, I can say the filament current is adjusted. That means current to the filament, so, this is filament.

So, this is filament, this filament current is adjusted by tuning the potentiometer, by sliding the potentiometer. Now, that means the light which is coming from the absorption filter is now passes through the light and that is where by identifying something from the light we will try to measure the temperature.

Now, this is the standard lamp that means light passes, right from the absorption filter passes through the lamp to a red filter. Next is the red filter, what is the function of the red filter? That means, the light which is now coming from the standard lamp will be now taken into the red filter and the red filter which will transmit or which transmits a narrow range of wavelengths to pass through the second lens into, in the eyepiece for visual comparison.

So, these are the different parts we have understood that means, the light which is coming now from the standard lamp, which will be transmitted by the red filter with a narrow range of wavelength to pass through the second lens of in the eyepiece for the visual comparison. So, now important part is the standard lamb, so light which is coming, so, we are interested in the temperature of a particular point or object, now that object or point will produce a light, visible light and that light is taken through the first lens. Lens is coming, the first lens, light is coming and that lens you know light which will come into the absorption filter. That filter is used to reduce the intensity of the light which intensity of the light which is coming.

Next, the standard lamp is there. So, the light which is coming from the absorption filter will passes through the light, standard lamp to the red filter. And red filter is used to narrow down the wavelength of the light which is coming from the standard lamp and the red filter will now direct the light to the second lens in the eyepiece essentially for the visual comparison.

Now question is, the standard lamp is connected if we go back to the circuit with another circuit and the current to the filament is adjusted by the potentiometer. So now I am writing something and that is very important to ultimately understand the how we can measure the temperature using this optical pyrometer. So now the current to the lamp is adjusted. So, the filament cannot be seen, we do not want to see the filament. Now the current to the lamp is adjusted so that filament cannot be seen. Now, that means, the filament appears as a dark line on a light background. If it is too cold, that means the background is light. If that filament is too cold, then the filament will appear the dark line.

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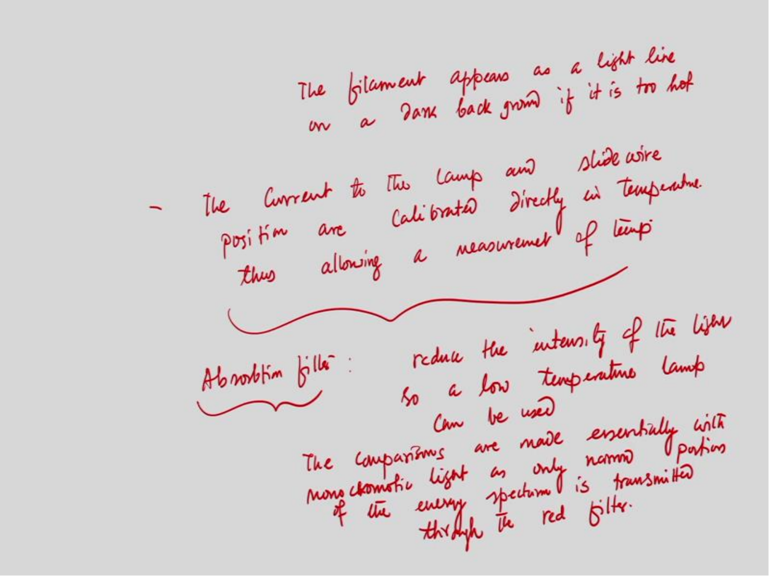
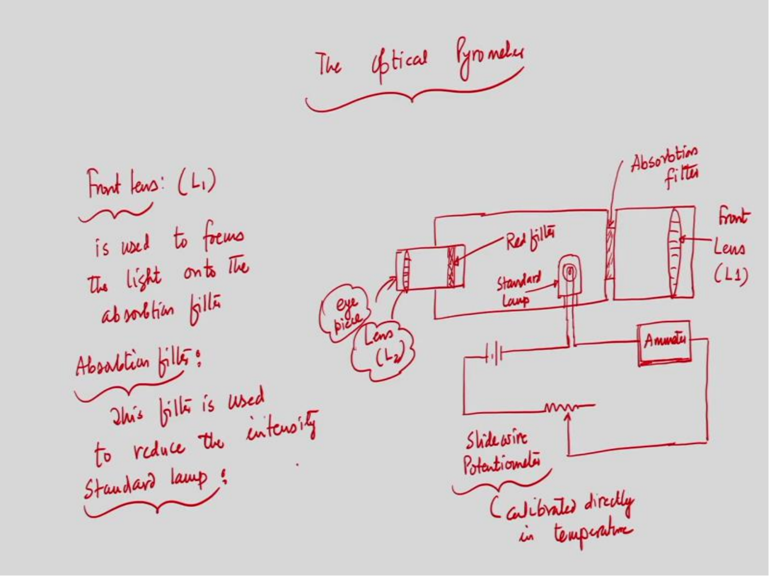


The filament appears as a light line on a dark background if it is too hot

- The current to the lamp and slide wire position are calibrated directly in temperature thus allowing a measurement of temp

Absorbtion filter: reduce the intensity of the light so a low temperature lamp can be used

The comparisons are made essentially with monochromatic light as only narrow portion of the energy spectrum is transmitted through the red filter.



The Optical Pyrometer

Front lens: (L_1)

is used to focus the light onto the absorbtion filter

Absorbtion filter:

This filter is used to reduce the intensity standard lamp;

Similarly, the filament okay, I am writing next slide, the filament appears as a light line on a dark background, if it is too hot. So, this now the filament will appear as a light line on a dark background if it is too hot, that means if it is too hot, then the background is dark and it will affect a light line. So, the current to the filament as I said, the current and the current to the filament, the current to the lamp and slide wire position are calibrated as I mentioned in the schematic directly in temperature.

Thus allowing a measurement of temperature. So, that means, the we are using that effect of radiation to measure the temperature. So we can control the slide wire position to control the current to the lamp and these two can be calibrated directly in temperature, what will be the temperature and we can measure the temperature, we can measure the temperature of the object that is what our interest, what was our interest.

As I, if I go back to the schematic, the absorption filter objective is to reduce the intensity of light, so, low temperature. So, I mean if we go to the next slide, so, this absorption filter, the objective is to reduce the intensity of the light. So, a low temperature lamp can be used and the comparisons are made essentially with monochromatic light, why? As only narrow portion of the energy spectrum is transmitted through the red filter, through the red filter.

So, that means the absorption filter reduce the intensity of the light, so the low temperature lamp can be used, not only that we are using, when you are comparing using the lens in the eyepiece, then we have another red filter. That means, the comparisons are made essentially the monochromatic light as the narrow portion of the energy spectrum, the red filter only can transmit the narrow portion of the energy spectrum.

So, this is important, the advantage is that using this method we do not require any direct contact to the object or point where the temperature is being measured and that is why it is purely non-invasive. But another problem, a limitation of this method is that the, you know, temperature of a point or object which you would like to measure should produce a visible light. If the temperature is unable to produce light, we cannot use this method to measure the temperature. So, this is only one of the limitations. So, with this, I stop my discussion today and we will continue our discussion in the next class. Thank you.