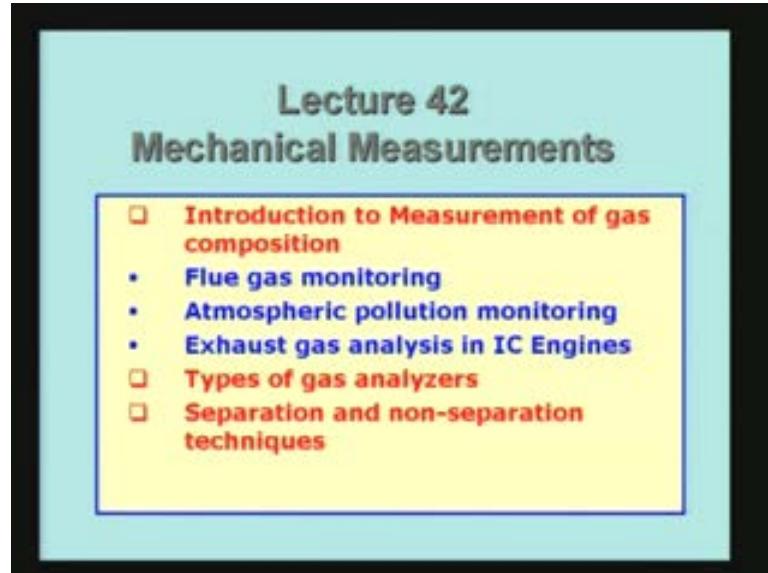


Mechanical Measurements and Metrology
Prof. S. P. Venkateshan
Department of Mechanical Engineering
Indian Institute of Technology, Madras
Module - 4
Lecture - 42
Measurement of Gas Composition

This will be lecture 42 on our ongoing series on Mechanical Measurements. In this and the forthcoming lecture we are going to look at a new topic that is introduction to measurement of gas composition.

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There are many situations which occur in mechanical engineering practice. We require to know the composition of gases as, for example shown here, flue gas monitoring. So, if a combustion device is operated the flue gases are generated in the combustion process, and the health of the combustion system is determined by the composition of the flue gas. If the flue gas contains too much of one or the other components, like for example, if Carbon monoxide is present in large quantity then it means combustion is not taking place efficiently, or it is not complete combustion so we would like to monitor Carbon monoxide concentration and find out whether the combustion system is functioning properly or not.

The next example I can take is, the case of atmospheric pollution. Now-a-days the atmospheric pollution has become a major concern because of the increasing number of vehicles, and also increasing population. Unsuitable things which are not required are present in large quantities in the atmosphere, and we would like to find out whether these are within the safe limits or not. So, atmospheric pollution monitoring is one of the most important things which we are going to be meeting in our normal day to day practice. Then there are cases of exhaust gas analysis in IC engines, because IC engines are major producers of these pollutants which ultimately end up in the atmosphere. We would like to find out whether the engine is working properly so that the exhaust gas does not contain the levels which are unsuitable for use.

As you can see the main reason for having taken these three examples is because of combustion, devices which use combustion and combustion devices are used in production of energy like in power stations and so on. So the flue gas monitoring becomes an important activity there, and usually it is done in the stack. Stack is the chimney through which the gases are going to be let out to the atmosphere and that is where you are going to sample the flue gas. For the second case, atmospheric pollution monitoring it is present all over the atmosphere along with air and we will have to find out how much is the concentration of the atmospheric pollutants. And this has this cannot be done by actually taking an instrument all over the place in the atmosphere, and making the measurement. One may have to go for a remote sensing method for this particular activity.

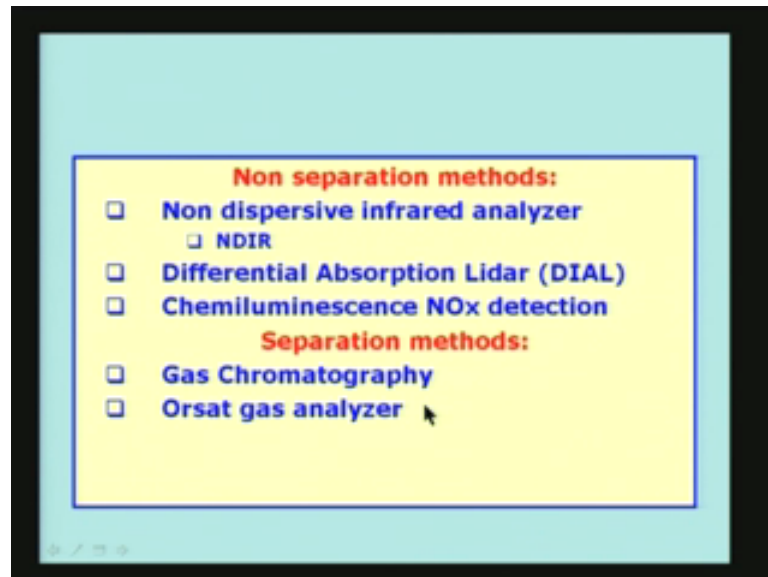
In the case of exhaust gas analysis in IC engines, it is possible to do it right near the engine as it is running. For example, it can be done when the engine is running when the vehicle may be moving or it may be done on a test bed. The exhaust gas analysis is being done as per law, where you take the car to the pollution monitoring center, and actually he will sample the exhaust gas coming from the tail pipe and make an analysis and tell you whether it is within the limits or not. This is just to have an idea about what are the circumstances in which you are going to make the measurements. What are the types of gas analyzers? We are going to look at the types of gas analyzers which are used.

Broadly, we can categorize them into two kinds; one is called the separation and the other one is called the non separation technique. Separation technique is where if you have for example a mixture of gases, you would like to separate the gases before finding out how much is the concentration of each one of them which means before the measurement, a separation of species is going to take place. In the non separation technique it is not necessary to separate them out. The entire gas mixture

is sampled and the constituents are measured when they are in the mixed state. So, the separation and non separation techniques are two main categories.

Let us look at the two methods, the non separation and separation methods, and look at what are the possible instruments or measurements or techniques which are available to us. One is called the non dispersive infrared analyzer. It is also referred as NDIR it is a very popular method.

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The basis for this method is, of course, using infrared radiation and its interaction with the gas molecules. So, if you want to measure the presence or absence of the gas or the amount of gas which is present you will have to make the infrared light pass through the medium where you expect the gas to be present and based on the measurement you will be able to say how much is the concentration of the particular specie in question. The second technique, I can put onto the non separation technique or non separation method is where you have differential absorption Lidar.

Lidar stands for light detection and ranging. The differential absorption Lidar is also referred to as DIAL, in short that is differential absorption Lidar. The method is one which uses remote sensing, that means that the measuring instrument is at some location which is not going to change or it may be onboard in an aircraft for example, and the aircraft is moving and as the aircraft is moving it is going measure the presence or absence of the gas or the amount of gas present in a particular gas of

interest of us by using what is called differential absorption. So this is the remote sensing application whereas the non dispersive infrared analyzer is usually a stationary one.

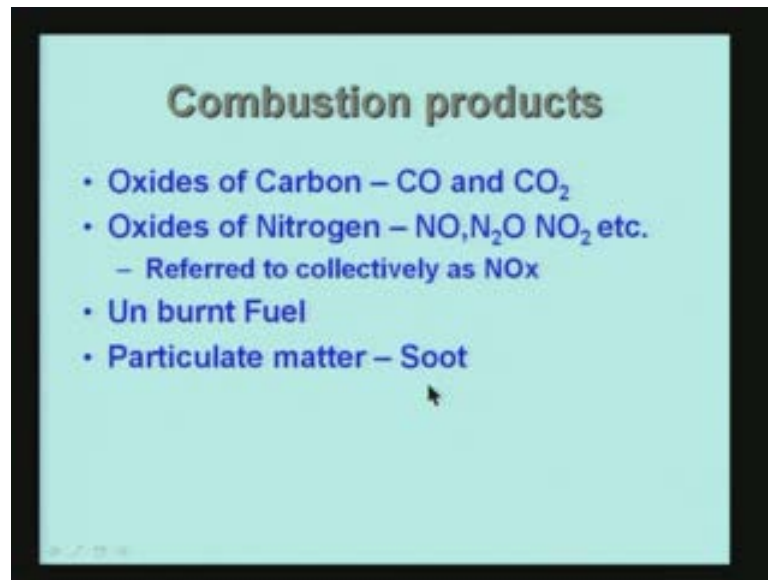
The third one I am going to look at is chemiluminescences or which is used for detection of Nitrogen oxides, the Nitrogen oxides are usually termed as NO_x. NO_x stands for all oxides of Nitrogen; it may be present in the particular sample of gas. For example, it may be Nitric oxide NO, Nitrous oxide N₂O, Nitrogen dioxide NO₂, and so on, and so forth. So it is usually clubbed together in this term NO_x and the detection of NO_x is very important because it is very highly polluting species which is basically present because of combustion devices.

Essentially, for example, the IC engine, gas turbines and so on are the producers or the ones which give rise to the presence of NO_x in the atmosphere. The second category of method is separation method. The method we are going to look at is the gas chromatography, which is very useful, very popular and which is easily available now-a-days. In the gas chromatography, the species are going to be separated by a certain technique called the chromatography technique, and the gases present in the form of mixture are separated into its constituents and these constituents come out of the instruments or come out of the chromatograph column.

In time the species will come one after the other. That means they are separated in time. The Orsat gas analyzer is a destructive method in the sense that the gas sample is collected, and it is absorbed in absorbing media and then the change in volume is noted and then the analysis is done by chemical separation, or chemical absorption method.

Let us look at the typical combustion products. Most of the times, we burn hydrocarbons, fuel is hydrocarbon which consists of hydrogen carbon, and possibly some other things also, like for example sulfur may be there and so on and so forth. But essentially combustion is of hydrocarbons, Hydrogen and Carbon are the most important parts and the combustion is done in the air, air contains Nitrogen and Oxygen, Nitrogen is coming into the combustion product through the air which is used for combustion.

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And if the temperature is suitable, Nitrogen will combine with oxygen either in the fuel or in the oxygen which is already presents in the air and at high temperature they will form some compounds. For example, oxides of Nitrogen are NO Nitric oxide, N₂O Nitrous oxide, NO₂ Nitrogen dioxide etc will all form and they are collectively referred to as NO_x. In the combustion products, the most important is the Carbon dioxide we would like to have, and probably water vapor because hydrogen is there in the fuel you expect water to be formed and water will be in the form of steam at high temperature and if the combustion products are cool of course, it will condense and water will become liquid water.

So you essentially expect oxides of Carbon, Carbon monoxide if the combustion is not complete, incomplete combustion will be indicated by the presence of Carbon monoxide and Carbon dioxide of course is the product of combustion which will form when the Carbon is completely burnt and converted into oxide and then oxides of Nitrogen if the temperatures are suitable, these species will be formed and at high temperatures Nitrogen oxide etc, will form and then of course the unburnt fuel the Hydrocarbon which we use as fuel itself will be present in some quantity because some fuel may not burn at all and such unburnt fuel can also be there.

For example, when I talk about combustion product I can talk about combustion of various types of fuels. It can be solid fuel or liquid fuel or gaseous fuel. So, depending upon the type of fuel I may have all of these which are mentioned here or some of these may not be there, it only depends on the particular fuel that is

used. And of course, there will be particulate matter or soot which is actually Carbon in the form of particles it is not completely burnt the Carbon is available in the form of particles and the presence of particulate matter in the form of soot is indicated by the color of the flame itself so that it will indicate whether the soot is there or not. So basically what we are talking about is the connection between the presences of the gases in the atmosphere, presence in the gases in the laboratory, because of combustion as one of the sources.

This is only one of the sources which we can think of; there are other sources as I said. Even humans and animals also give rise to lot of gases which are going to be in the atmosphere. After all we breathe oxygen and give out Carbon dioxide which is also known to everybody. Therefore Carbon dioxide present in the atmosphere is because of the living beings including humans and animals. And of course animals also give rise to other gases which are present in the form of methane and so on and so forth. Even vegetation when it rots, or when it undergoes a slow reaction in the atmosphere degradation gives rise to lot of waste gases.

So, the idea is that we would like to monitor or find out the amount of this product present in the atmosphere, and we would like to look at various methods which we can use for doing so. For example, we can see the emission limits which are given in this table as required by law. These are presently followed by law in India so we have the Bharath standard 1 then Bharath standard 2, 3 and so on. These are the standards which are going to be followed by vehicle manufactures in the design of the vehicle. For example, if I take Carbon monoxide present in the exhaust gas the limits are specified here in g per km.

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Examples of Emission limits			
	CO (g/km)	HC + NO _x (g/km)	
BS I	2.72/3.16	0.97/1.30	
BS II	2.20	0.50	
		HC	NO _x
BS III	2.30	0.20	0.15
BS IV	1.00	0.10	0.08

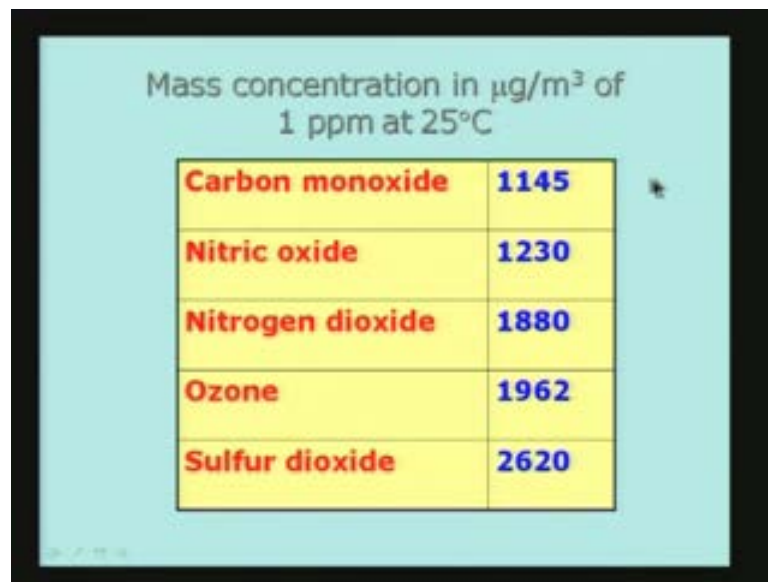
Lower values are for type approval and the higher values are for conformity of production

So, if you run the car, or engine for one kilometer under specified conditions the amount of Carbon monoxide it can emit is limited by this number 2.72 and 3.16. And if you look here, the lower values are for a type approval. That means, it is at the stage of the approval of the vehicle and the higher values are for the conformity of product which means at the production time this can be slightly higher. So, 2.73 to 3.16 you see that the emission in grams per kilometer is limited to 2.72. And if you look at the different standards which are being mentioned here, these values are actually coming down. These were the standards available or specified earlier and now it has come down to 2.2 in the case of BS2 and in BS3 it is going to be more or less the same, but in BS4 it going to be brought down to a level equal to 1.000.

Now one may want to know what g per km stands for. So g per km is measured under specified conditions. Either it can be done by actually running the vehicle and making the measurement or it can be done by running it on a test bed with power being produced which can be monitored by using a dynamometer and then you find out the specified amount of Carbon monoxide and you measure it over a period of time and then you relate it to the grams per kilometer. The second thing is Hydrocarbon, this is the fuel itself petrol or diesel or whatever it is plus the NO_x. The NO_x is produced during the combustion process. Again it is given in g per km and you can see that the value are coming down steadily, and in the BS1 and BS2 HC plus NO_x are clubbed together and we have 0.97 and then it has come to 0.5.

But in the BS3 and BS4, HC and NO_x are now separately specified. So Hydrocarbons should not be present more than 0.2 g per km, and NO_x is all the Nitrogen oxide less than 0.15 g per km as specified. So you see that the emission limits are specified by law, and in order to meet with these limits, we have to design the vehicles or the combustion devices properly, and in order to monitor we need measurement techniques. So that is how we are building up a case for the need for measuring the gas composition. Let us look at the various ways for representing the gas concentrations.

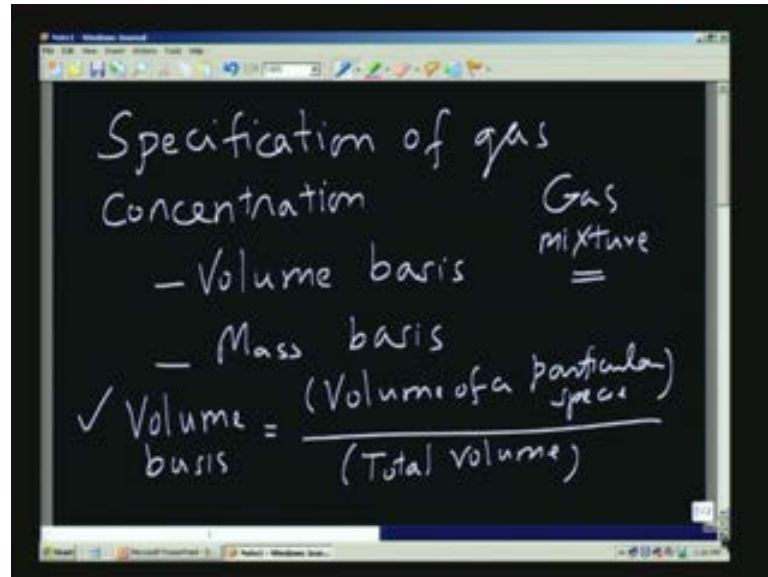
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Carbon monoxide	1145
Nitric oxide	1230
Nitrogen dioxide	1880
Ozone	1962
Sulfur dioxide	2620

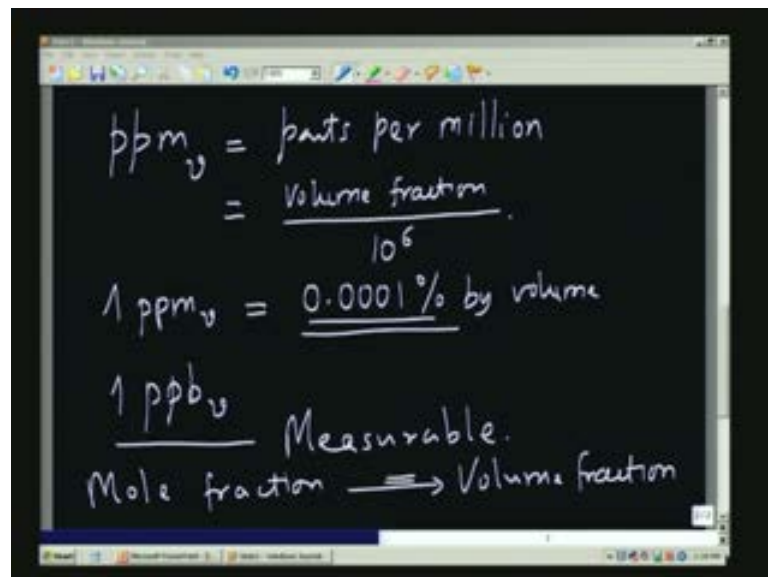
There are mainly two ways of specifying gas concentration, one on volume basis, and the second one on mass basis. For example, volume basis I can specify it as so much of particular gas of interest to us. For example, I can put it in the following way. So on volume basis the volume of particular specie divided by the total volume. So I am actually talking of a gas mixture, because seldom are we going to get a condition where the gas is going to be present independently and separately, so we have a mixture of gases and in that particular gas mixture, I would like to find out what is the fraction of the volume occupied by the particular gas. Basically the idea comes from Dalton's law which is very familiar to us in thermodynamics. We have two ways of looking at gas concentration. It is either the partial volume the volume occupied by a particular specie in the entire volume or we can look at it as a partial pressure.

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The pressure basis is also possible. Of course, these two are interconvertible and generally the volume basis is what is normally used in practice. And it is also represented in a slightly different way. We want (Refer Slide Time 22:34) to represent in the following form ppm volume basis means parts per million, this will be volume fraction so I am just going to divide it by 10 to the power 6.

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The reason why I am going to take it in this particular form is, because when we are talking about the presence of gases in the atmosphere or exhaust gases, and so on, the amount is very small. The amount of the gas which I am talking about for example, Carbon monoxide the amount Carbon monoxide present in the atmosphere is so small that it is better to divide by 10^6 so that you get in terms of parts per million. So parts per million will be a whole number that is the whole point. So, for example, 1 ppm volume basis is also like 0.0001% by volume.

So, when you are talking about very small quantities, it is better to use a unit which is of appropriate size, and therefore I am going to use parts per million as a possible use. So 1 ppm is also 0.0001% by volume, and the reason why we are using this unit is because we are talking about very small quantities we are going to talk about so use a unit which is also appropriate so that the number will be a whole number instead of being a very small fraction.

If the volume fraction is much smaller than even 1 ppm, we can even have one parts per billion which is represented as 1 ppb or even smaller, so it could be one parts per trillion and so on and so forth. And the important point is to note that such levels are measurable. With modern measurement techniques it is possible to measure such small quantities of volume fraction of gases present in a large volume of gas. The second point is that the volume fraction is same as the mole fraction. So, mole fraction or on the basis of mole is identical as the volume fraction. Now let us look at, how we are going to convert this to mass basis. This is the second way of representing the presence of particular gas specie and we would like to find out how to represent that.

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Mass basis
SI units kg/m^3 (density)
Usually we use mg/m^3 as the appropriate unit.
Ideal gas relation:
$$\text{ppm}_v = \left(\frac{\text{mg}}{\text{m}^3} \right) \left(\frac{273.15 + t}{12.187 M} \right)$$

temp. of gas sample
molecular weight

In principle, if I am going to use SI units, this will be simply given by kilogram per cubic meter that is the unit of density. That means, I would like to find out what is the mass of the particular specie in unit volume. The unit volume here represent to the volume of the gas mixture. So if I am taking 1m cube of the gas volume what is amount of the particular specie of gas or what is the amount in kilo grams present in that particular sample. But in practice, as you saw earlier we were talking about ppm and ppb levels, the amount of gas present is very small, so usually we use micro gram per m^3 as the appropriate unit. So, if I am going to represent either on the volume basis or the mass basis, I can convert one to the other, and it is very easy to do so.

I will just give the formula, it is based on ideal gas relation. And if I am given in mass basis, to convert it to ppm volume basis, I will have to just take the value of the mass density in mg per m cube, instead of micro gram, I am using mg here but of course, you can always add one more factor so 273.15 plus t in degree centigrade because, it depends on temperature and divided by 12.187 times the molecular weight. So the temperature is, the temperature of the gas sample. The reason why the temperature occurs is because the volume of the gas is to be measured at the temperature which is being specified, and at that temperature the volume depends on the temperature according to the ideal gas law. And we are assuming that the pressure is 1 bar. If the pressure is not 1 bar it can also be corrected by appropriately taking into account because it is the linear function of the pressure.

And the molecular weight is the molecular weight of the species. So we need to know the molecular weight and then all we have to do is, to substitute here and we will be able to get the appropriate value. Let me take an example. For example, if I have NO_2 and the concentration is given as 20 mg per m cube, this is the mass basis, volume basis and all I have to do is to use that formula, this will be 20 multiplied by the temperature if I am assuming the temperature is 25 degree Celsius this will be 273.15 plus 25 and this is nothing but your temperature in Kelvin.

So, I am just converting degree Celsius to degree Kelvin divided by that factor 12.187, multiplied by the molecular weight that is known to be 46.01, this is the m for NO_2 and this will work out to 10.6. So the volume basis is 10 ppm level and the mass basis is about 20 mg per m cube. So instead of milligram if you want to put it as micro gram you have to multiply by 1000 then it will be 20000 microgram per m cube. It is rather a high level of pollutant concentration. Of course, you can also convert it from ppm to mg or microgram per m cube and the same formula can be used for that purpose.

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$$\text{NO}_2 \rightarrow 20 \text{ mg/m}^3 \text{ (mass basis)}$$

$$\text{ppm}_v = \frac{(20) (\overbrace{273.15 + 25}^{\text{temp in K}})}{(12.187) (\underbrace{46.01}_{\text{m for NO}_2})} = 10.6$$

Let us look at the mass concentration of various species. If 1 ppm of the particular species is present in the atmosphere which is at a total pressure of 1 bar or 1 standard atmosphere and the concentration is going to be 1 microgram per m cube.

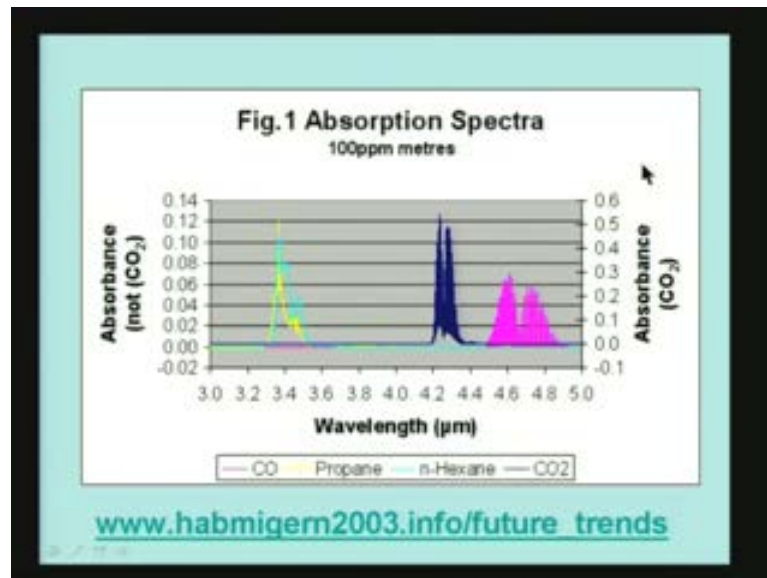
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Mass concentration in $\mu\text{g}/\text{m}^3$ of
1 ppm at 25°C

Carbon monoxide	1145
Nitric oxide	1230
Nitrogen dioxide	1880
Ozone	1962
Sulfur dioxide	2620

You see that the amount of ppm for different species is specified here. For Carbon monoxide corresponds to 1145, Nitric oxide it comes to 1230, Nitrogen dioxide this is NO_2 is 1880, ozone 1962, Sulfur dioxide 2620. So you see 1 microgram per m cube is a small amount we represent, the parts per million is quite large. These are the units which are normally used in practice. Now let (Refer Slide Time: 28:40) us look at what are the various ways of making measurement of gas concentration. There are two ways of doing it, one is the separation method and the other one is non separation method.

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Before we go into that, let us look at what could be the types of measurement which could give the gas concentration. So I have an absorption spectrum of a mixture of gases. The terms used are, the 100 ppm is the 100 parts per million are the various gases present in the total atmosphere and 100 ppm meters means, it is the product of the concentration times the path length. So how do you take an absorption spectrum? You pass an infrared beam through a certain thickness of the medium and that stands for the meters, 100 ppm in meters can be obtained by 1 ppm over a 100 ppm length or 10 ppm over 10 meter length or 100 ppm over 1 meter length.

So this can be this can be obtained, by adjusting the concentration times the path length product to 100 ppm meters. So you can either very high concentration with a short path link because they are all equal in length. Because, when the infrared beam passes through this gas it gets absorbed, the absorption is selective, and it is depends on two factors One is the wavelength, and the other one is the absorption coefficient of the particular specie which is present and different gases are going to absorb in different parts of the spectrum.

For example, CO₂ is here, CO is here and is not very far from it. So CO absorbs in this band, CO₂ absorbs in this band but if you look at propane and n hexane both of them have overlapping absorption. In fact, if I show other gases like water vapor and Nitrogen oxides and so on, and they will also show some overlap with other species. The wavelength starts from 3 micrometers; this is the wavelength of the radiation passing through the particular specimen, or the sample through which the

measurement was taken. So it is from three microns to five microns. This is the mid infrared range and the scales are different. For other than CO_2 , this scale is valid and for CO_2 this is valid. Therefore, CO_2 has much more absorption than the other species as you can see here.

But what we are going to notice here is that, there is a specific wavelength at which the particular specie will absorb and it will not absorb at other wavelength. That gives me one way of doing the measurement of gas. By using the appropriate infrared radiation of appropriate wavelength, I will be able to select the particular gas which is going to absorb and all other gases will be in active that means they are not going to absorb. So this separation is not physical, but it is done by wavelength. The wavelength will separate the species.

It will appear as though for that particular wavelength the other species do not exist. That means that it is for the non separation technique as well as physical separation is concerned but it is separated, because of the wavelength different wavelengths are absorbed or radiation at different wavelengths are absorbed by different species. Therefore if I am interested in CO_2 , I will use an appropriate wavelength and it will be absorbed only by CO_2 but other gases will not absorb. Therefore whatever absorption I get, is related to the presence of the CO_2 in the mixture. So the separation is done by the absorption technique which is wavelength specific and not physical. Ultimately, we are going to separate out the species not physically but in the wavelength type.

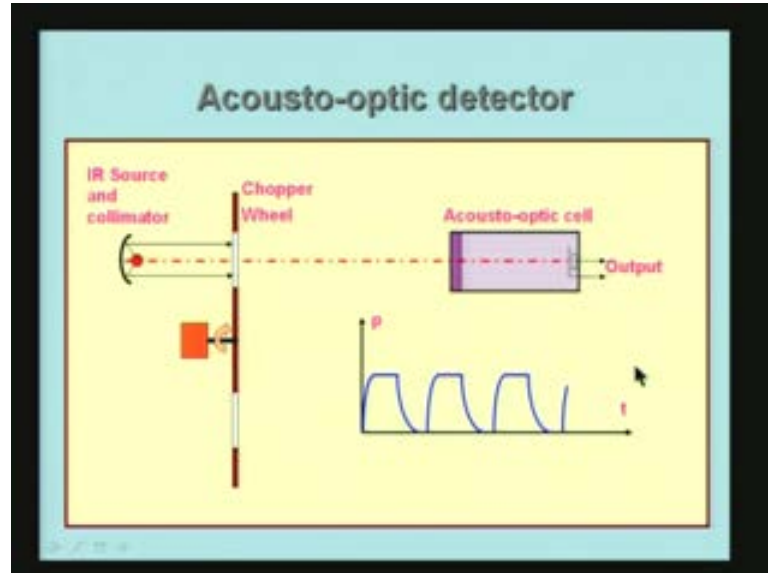
What is the use of this particular sketch?

The use is to demonstrate that, we can do the separation by looking at the spectra and by using the appropriate wavelength I can do that. This is one way of looking at it. Another way is, is it possible that I can do the same thing by a different technique? What do I mean by that? Suppose I want to use the wavelength specific radiation I have to have a spectrometer or I have to have a source which will emit only in this region for example if it is CO_2 . If it is CO , it has to do only in this region. That means, I must find a source which is going to be emitting radiation only in that particular wavelength of interest so that I can do that, and that can be done in a spectrometer. In a spectrometer what we have is a broad band source or a source which will radiate all over the wavelength scale. But by using a spectrometer, we are going to divide the light into its spectral components by some suitable means.

For example, I can use a prism, I can use a grating and associated optics so that I can get whatever wavelength I want from the instrument, or I can also use what is

called Fourier transform infrared spectrometer which will do the separation in a time scale, that is, the separation will be done over time. One way is to use a spectrometer. In the spectrometer, because we are going to separating out the wavelengths into the spectrum of wavelength it is called dispersive instrument. The spectrometer is a dispersive instrument, because the light is separated into its wavelength components. In the non dispersive measurement I am not going to separate the light also, but by clever arrangement, I will be able to use the NDIR or the non dispersive instrument to actually measure the presence of the gas by a simple technique. Let us look at the principle which is going to be used in that particular case. So I use what is called Acousto-optic detector that is the heart of the matter.

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The Acousto-optic cell consists of a small cylindrical vessel with a transparent window through which the infrared beam can pass into the cell and the Acousto-optic cell is a volume of gas and the gas which is contained inside is such that it will absorb the radiation which we want it to absorb. For example, if you fill this with carbon dioxide it will absorb only the radiation which is absorbable by the carbon dioxide and the rest will not be absorbed. And what happens if radiation is absorbed by this gas inside? The gas pressure temperature will go up because it absorbs radiation, and when the temperature goes up the pressure will tend to increase. Suppose, I have a radiation which is chopped using a wheel with a window, whenever the window comes in front of the IR source the radiation will

pass through to the acoustic cell and whenever the window is not there but the wheel is there then there will be no radiation coming here.

So, if you look at the pressure which is monitored by the output of whatever is shown here, this is a pressure transducer, we have already looked at pressure transducers earlier, it could be a capacitor for example. So the capacitance changes and that will give you an electrical signal. So when the light is passing into the Acousto-optic cell the pressure goes up slowly, it builds up and then it reaches a maximum value and there is a hole here which is going to come in and leave, during this process it is going to be illuminated, and the pressure remains at this. Once the hole has passed the source, the pressure starts decreasing because, there is no radiation coming inside this. Again this repeats itself, because I am rotating this wheel by using an electric motor and the IR source I am going to get a correlated beam here and that passes this hole, and I can get an output from this transducer which will vary as shown here.

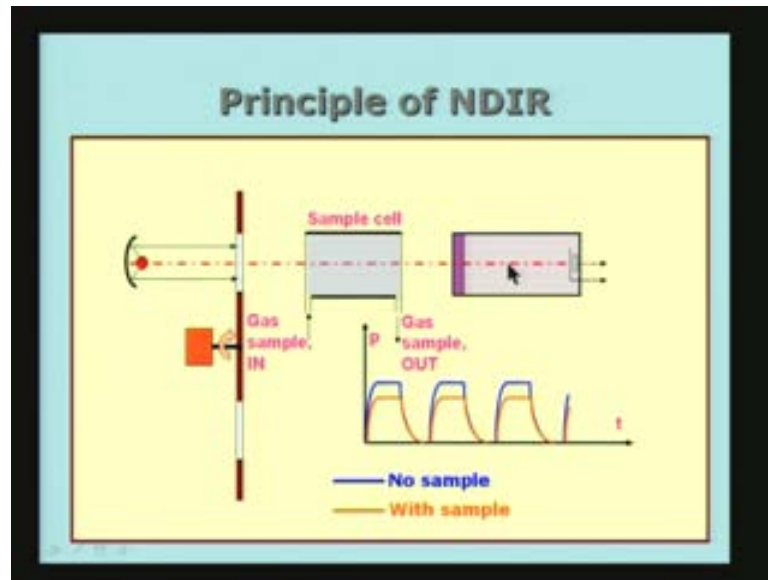
This is the pressure versus the time signal which you get from the Acousto-optic detector. The Acousto-optic detector is a detector which detects the radiation of particular wavelength of interest to us. For example, if I want carbon dioxide the wavelength corresponding to this region, I use carbon dioxide inside the cell, if I want carbon monoxide I use carbon monoxide inside the cell and if some other gas is required so the gas contained in the Acousto-optic cell is the gas, which I am going to detect. So, Acousto-optic cell is also an Acousto-optic detector for particular gas specie. What is the use of this?

So, if I have the following, in front of the Acousto-optic cell, if I keep a sample cell where, I am going to go allow the gas sample to go in and out, this is the sample in which I want to find out whether there is carbon dioxide or whatever species I am interested in. So what happens if you put the sample cell here? The gas of interest to us, which is in this cell absorbs some of the radiation. Therefore, the radiation received by the Acousto-optic detector is reduced, because it transmits less than 100% of what is going to fall on the sample cell therefore it is reduced. Therefore the amount absorbed by the gas which is present here is of the particular species I am interested in.

Suppose, I want to measure carbon dioxide in the sample cell so some carbon dioxide is here, and there is also some carbon dioxide in this cell, and this will absorb whatever is not already absorbed by the sample in the sample cell. Therefore the output of this Acousto-optic detector will be smaller. This was the output when there was no sample cell, or when there was no carbon dioxide in this particular

cell. If there is carbon dioxide present here, this signal will go down. So this difference between the signals from this value to this value is due to absorption in the sample cell. So in the sample cell you can find out what is concentration of the gas.

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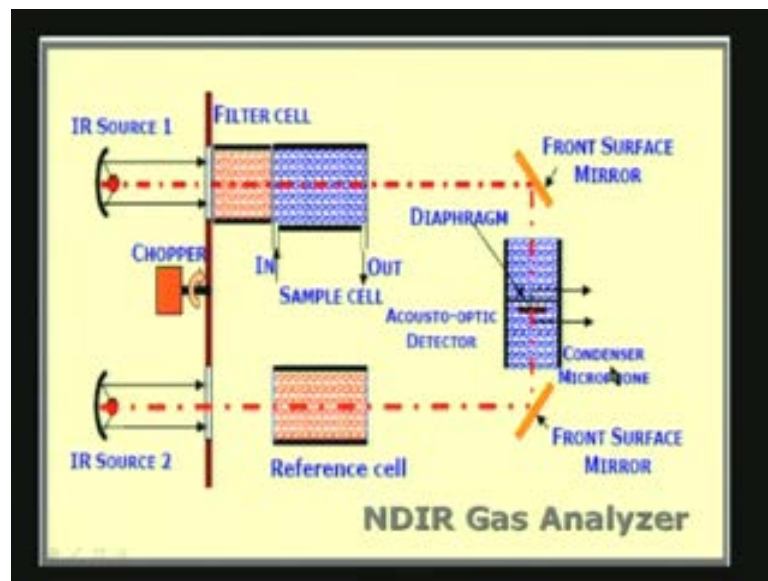


For example, I can do the following, I can fill the sample cell with different known concentration of carbon dioxide and then I can find out what is the reduction in the signal and then I can calibrate it. Therefore I can take standard samples of carbon dioxide of various concentration or mixture containing a certain proportion of carbon dioxide, and I can do this experiment and once for all calibrate the instrument. Without sample and with sample there is change in the output of the Acousto-optic detector and what you notice is that, I am using the light coming from the source without converting it to any spectrum, I am using all the light which is coming out.

The selective absorption is done by the detector itself. The detector itself is a selective absorbent. It absorbs only the wavelength of interest to us and the sample cell if it contains the same absorber this Acousto-optic detector will sense carbon dioxide present in the sample cell. Now let us look at how the NDIR gas analyzer is actually constructed. It consists usually of two sources; IR source 1 and IR source 2. We use a reference cell, we use a sample cell, we also use what is called as filter cell. So the filter cell is an important part of the thing.

If you remember when we talked about absorption, for example, this is the characteristic of carbon dioxide, carbon monoxide etc. Suppose you take a look at these two propane and n hexane both are going to absorb in the same region but to a different extent. There may be some overlap, there may be some region where both will absorb and in some region only one will absorb so what I can think of is the following.

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Suppose, I put a filter cell in front of the sample cell which contains a large concentration of n hexane. For example; propane and n hexane, I want to differentiate or I want to measure the presence of propane when n hexane is also present all I have to do is use a filter cell with large concentration of this so that whatever absorption can take place in n hexane will be totally absorbed in the filter cell. So the filter cell will remove all the radiation which is absorbable by one or the other interfering gases. Therefore, what is incident on the sample cell is only the radiation which is not absorbed by both the gases.

That is how you filter cell is made.

The filter cell consists of a large concentration of gas which going to interfere with the particular species in which we are interested in. Let us see how the NDIR gas analyzer works. The first IR source 1 it passes through the filter cell then through the sample cell and there is a front surface mirror so that the radiation is allowed to fall on an Acousto-optic detector, this is a Acousto-optic detector with a diaphragm in between and there is condenser microphone, and now on the other side is the

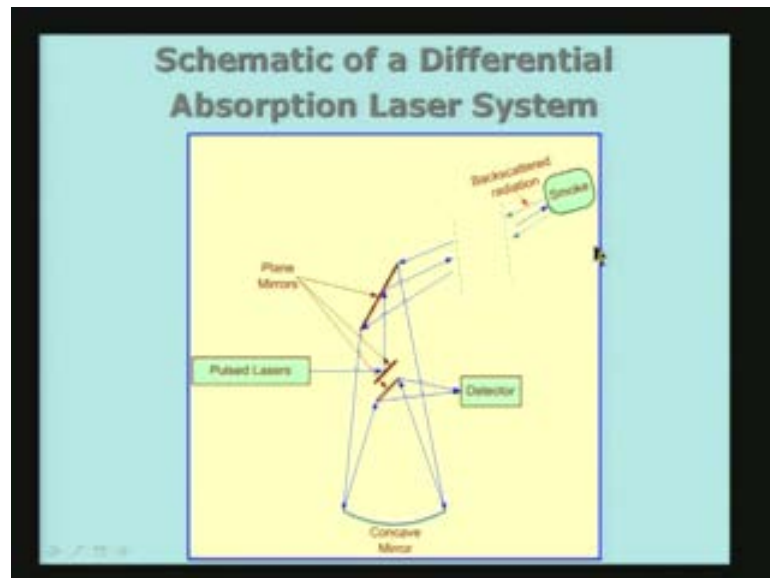
reference cell, the reference cell does not contain the gas we are interested in therefore the full intensity is felt. So the difference between the pressure developed on this side and this side is the actual output.

So the pressure difference is like in the previous case is with and without sample. So without sample and with sample is not done separately twice but it is done in the same instrument, this is without sample and this is with sample. So you have dual beam NDIR gas analyzer. That means it is two beams of IR source which are of course, matched perfectly so that they have equal intensity and so on. So the diaphragm is going to be the communicator between the two parts of the Acousto-optic detector. This diaphragm will deflect and the deflection of the diaphragm is going to be measured by the electrical output.

The entire thing works with a chopper wheel which is chopping the radiation in the AC mode or Alternate current mode so the condenser output is also an alternating voltage output. So the magnitude of the voltage output is directly related to the concentration of the particular gas which I am interested in. The NDIR gas analyzer is very popular and is used for measurement of combustion gases. In most IC engine laboratories we have NDIR which is used for CO, CO₂ and monitoring the concentration of various species.

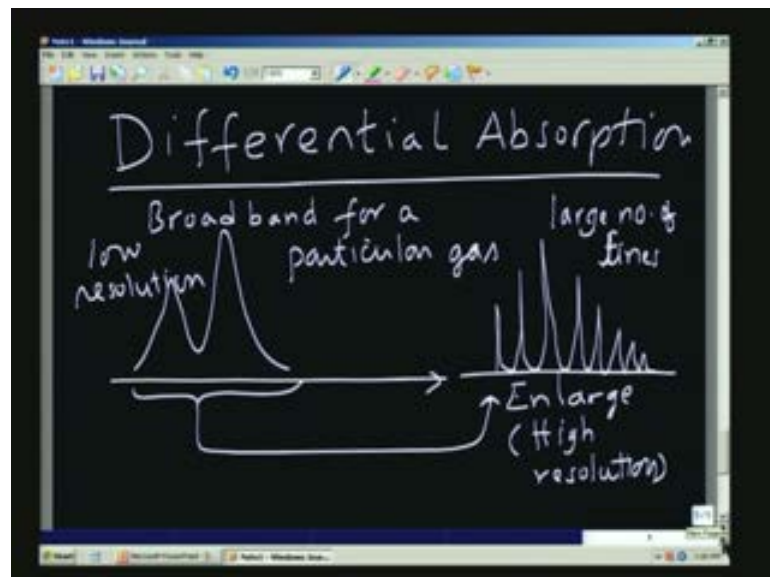
But you will also notice that, in the case of Acousto-optic detector we require different detectors with different gases being present so that they can measure the concentration of different gases. So one detector will not work for all of them, you need two or three different detectors so that you can measure the species of different gases if they are present at the same time. That is the first example, the NDIR. NDIR is very popular and it is available commercially and it can be set up in any laboratory for making measurement.

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The second system I am going to look at, is the remote sensing. The schematic of a differential absorption laser system is shown here. Let us look at the basic idea of differential absorption system. What is this differential absorption? We showed the spectrum. The spectrum consists of the following for any gas. This is a broad band for a particular gas.

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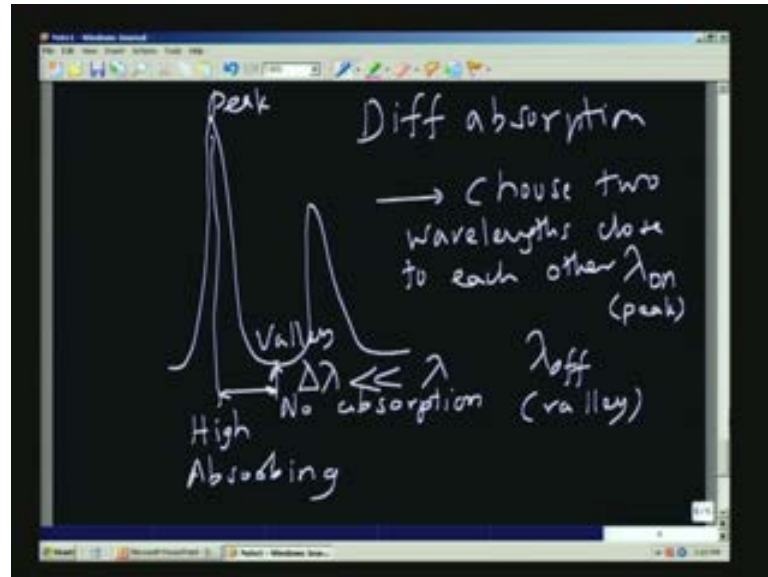


For example, I may be talking about CO_2 , CO , N_2O , and NO etc. But if you take this, and enlarge, this is also a low resolution spectrum. So, if I enlarge that means I am going to take a high resolution, it will show something like this. In fact, if you go back to the figure there, you see all these are lines here, there are lot of lines close to each other.

This has got a large number of lines close to each other. Therefore we notice that, if you look at the height of this the height represents the amount of absorption or in this case, emission. They are going to be mirror images of the same so it does not matter. Therefore, at this wavelength corresponding to the peak, it absorbs or emits radiation. And if you go here in the valley, very little of absorption or emission is going to take place.

So, I can identify if I have an absorption band or emission band something like this, then this is highly absorbing, and here there is no absorption or it is very little, and the difference here, I will say $\Delta\lambda$ is very small compared to λ . The wavelength difference between the peak and the valley this is the peak and this is called a valley it is very narrow. So, if I have radiation falling on this gas at the wavelength corresponding to the peak it will be absorbed very highly, and if the wavelength of the radiation is just a little bit away from that, and it is in the valley it is not going to be absorbed at all. So, differential absorption means, choose two wavelengths close to each other one at the peak which I will call as λ_{on} close to peak and the other one I will call it as λ_{off} and this is called the valley, it is a very interesting technique.

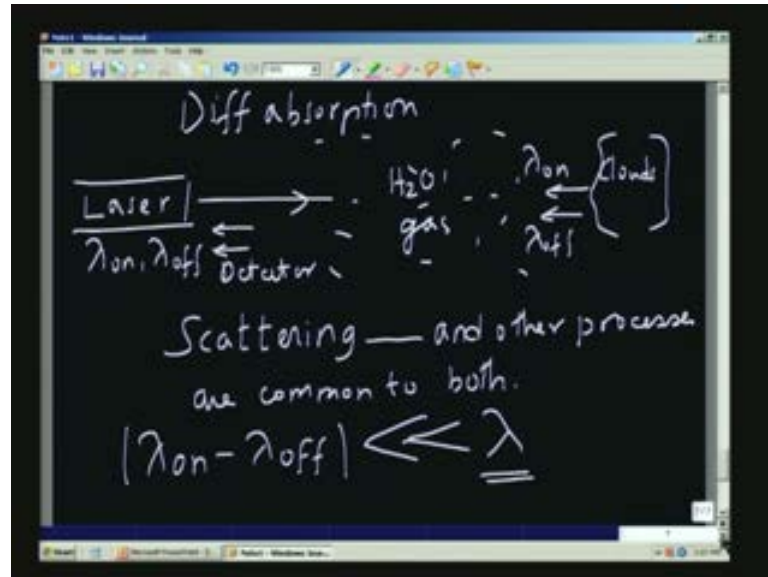
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So what I am going to do is, I am going to use two beams of light and in this case, I am going to use lasers which are very close to each other in wavelength. That means, that λ_{on} and λ_{off} are very close to each other. The reason why they should be very close to each other will become clear later. So the point is that, if the path through the gas is covered by two beams of radiation which are identical in every respect except that one has a wavelength equal to λ_{on} and the other one is going to have a wavelength equal to λ_{off} these two are going to undergo different amounts of absorption and that is why it is called differential absorption. One is absorbed highly, and the other one is not at all absorbed.

Therefore by measuring the ratio of these two or the difference between these two we will be able to find out how much of the species is present in the atmosphere. This is just the broad outline of the method. Let us look into how it is going to be actually done. I have got a laser source so it will have λ_{on} and λ_{off} both, and it is going to be leaving the laser it will go, and in the atmosphere I may have some clouds, for example. They will reflect the light, so λ_{on} and λ_{off} both are going to be reflected and when they come back here, I will find out by means of a detector. This is the intermediating atmosphere which is full of gas of our interest. For example, I may be interested in finding out how much of moisture is present in the air, how much of water vapor for example H_2O .

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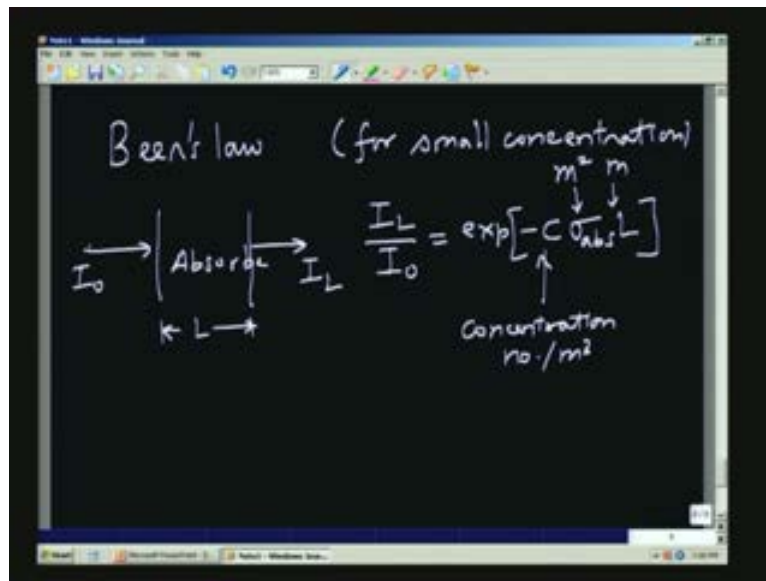
Of course, in this case when you want to measure the H₂O concentration it is a useful gas, because we want water. It is not a pollutant it is actually a useful thing. So, I want to find out how much water vapor is entering into the atmosphere by measuring. I will choose the two wavelengths such that one of them is highly absorbed the other one is not absorbed. And the second point is, if these two frequencies are very close to each other. The other properties, for example, is scattering where because of the particles present in the atmosphere the radiation is scattered, and also when the laser beam goes all the way from the source and gets reflected from the clouds there are lot of attenuation, because of the beam divergence then scattering out and so on so the scattering and the other processes like beam broadening and so on are common to both because scattering is very highly sensitive to wavelength, but because the two wavelengths are very close to each other.

Practically, there is no change in the lambda. This is a very small delta lambda. Lambda_{on} minus lambda_{off}, if I do that it will be very small compared to lambda that is what we are talking about. This lambda is nothing but the average of the two lambdas. Therefore because the lambdas are very close to each other, scattering and the other beam spoiling processes are common, and therefore the only difference between the two will be the differential absorption. The only thing which is different is the differential absorption because lambda_{on} is absorbed highly and lambda_{off} is not at all absorbed. Therefore, if I look at the difference between the

two signals which I am going to get, I will be able to find out the concentration of the particular species.

Here is one expression which will be useful. It is called Beer's law which is valid for small concentration what we usually expect in the atmosphere. We are talking about parts per million and so on.

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The image shows a handwritten diagram on a blackboard illustrating Beer's law. On the left, an arrow labeled I_0 points towards a vertical rectangle labeled "Absorber". Below the rectangle, a double-headed arrow labeled L indicates the path length. An arrow labeled I_L points away from the right side of the rectangle. To the right of the diagram, the equation is written as $\frac{I_L}{I_0} = \exp[-C \sigma_{abs} L]$. Above the σ_{abs} term, there are two arrows pointing down to it, labeled m^2 and m . Below the C term, an arrow points up to it with the label "Concentration no./m³".

So, if radiation leaves a point and goes through an absorber and comes out, if this length is L , if the intensity is I_0 , the I at L so we have, I_L by I_0 is e to the power of minus the concentration of the species multiplied by what is called the absorption cross section multiplied by the path length. So this is the concentration, it is number per m cube, this absorption cross section is given in m square and the path length is in meters. Thank you.