Electrochemical Technology in Pollution Control

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Lecture – 22
Ion selective electrodes 3

Greetings to you, we will continue our discussion on a Ion selective electrodes.

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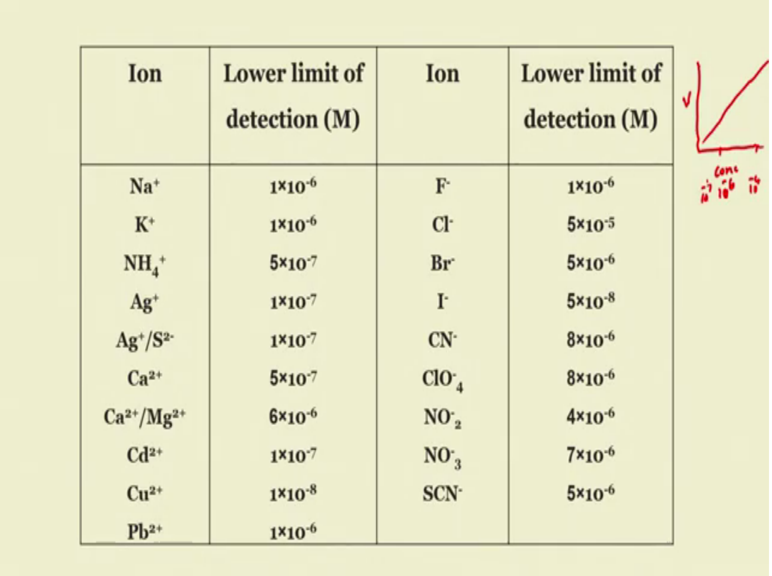

Ion	Lower limit of detection (M)	Ion	Lower limit of detection (M)
Na^+	1×10^{-6}	F^-	1×10^{-6}
K^+	1×10^{-6}	Cl^-	5×10^{-5}
NH_4^+	5×10^{-7}	Br^-	5×10^{-6}
Ag^+	1×10^{-7}	I^-	5×10^{-8}
Ag^+/S^{2-}	1×10^{-7}	CN^-	8×10^{-6}
Ca^{2+}	5×10^{-7}	ClO^-_4	8×10^{-6}
Ca^{2+}/Mg^{2+}	6×10^{-6}	NO^-_2	4×10^{-6}
Cd^{2+}	1×10^{-7}	NO^-_3	7×10^{-6}
Cu^{2+}	1×10^{-8}	SCN^-	5×10^{-6}
Pb^{2+}	1×10^{-6}		

And in my last class, I had taught you about the limit of detection of the several ions, using ion selective electrodes I had also told you that it is there we do not know any other technique, which can determine the concentrations of the metal ions as well as anions at these concentrations.

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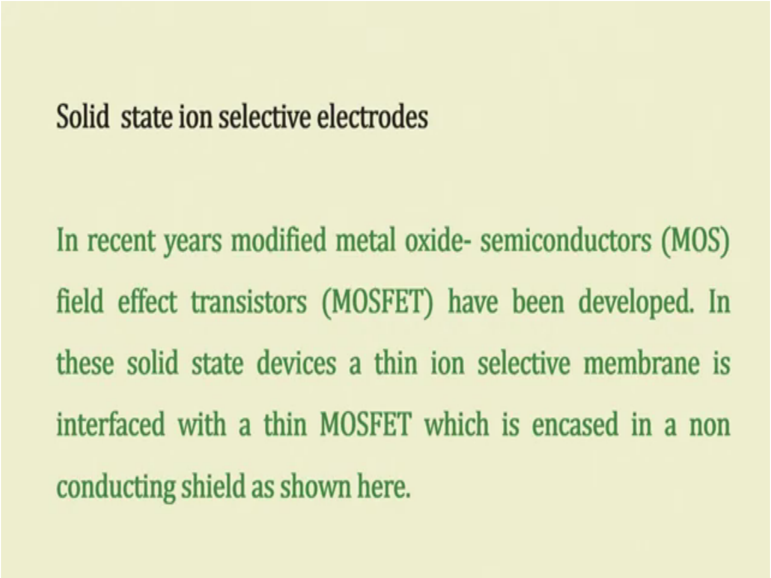

Solid state ion selective electrodes

In recent years modified metal oxide- semiconductors (MOS) field effect transistors (MOSFET) have been developed. In these solid state devices a thin ion selective membrane is interfaced with a thin MOSFET which is encased in a non conducting shield as shown here.

So, now I am going to describe to you the solid state ion selective electrodes, there what happens is in recent years lot of research has gone into making Metal Oxide Semiconductors that is known as MOS Metal Oxide Semiconductors and these are basically semiconductors with field effect transistors.

So, they have specific properties for conduction of the electrons and ions etcetera. And they are popularly known as MOSFET semi Metal Oxide Semiconductor Field Effect Transistors have been developed and these are something like solid state devices for carrying out the chemical analysis etcetera.

They have been used quite a lot here a thin ion selective membrane thin means, really thin of the order of about 10 raise to minus 4 centimeter less than, micron size maybe below micron size that is; interfaced with a thin MOSFET that is; the base which is encased in a non conducting shield.

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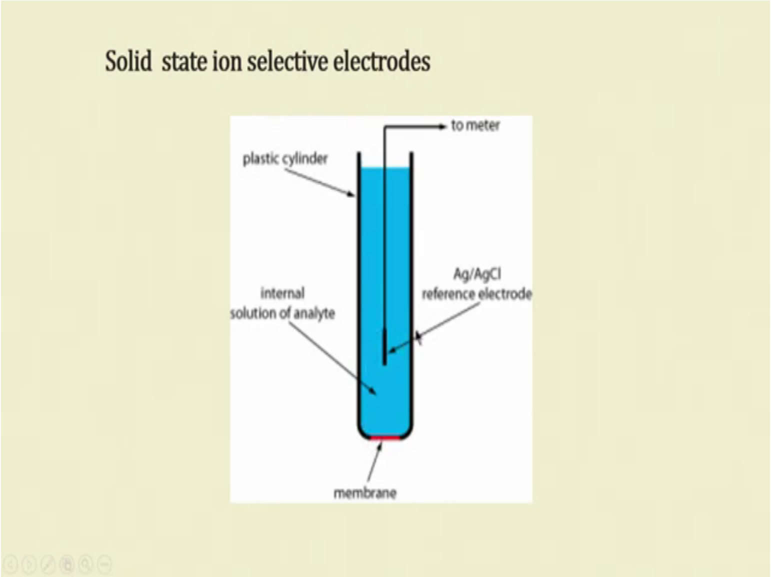

Solid state ion selective electrodes

I will show you a figure something like this here you see the membrane at the bottom red color. So, this contains the solid state ion selective electrode with a metal oxide semiconductor both are shield here in the membrane. And here other things as usual this is an internal solution of the analyte, this is silver silver chloride, reference electrode and this is the basically a plastic cylinder small cylinder and this whole thing looks like an electrode ok.

And this is shield etcetera etcetera and then it goes to meter and there we have a connection from here one more for the measurement completion of the circuit.

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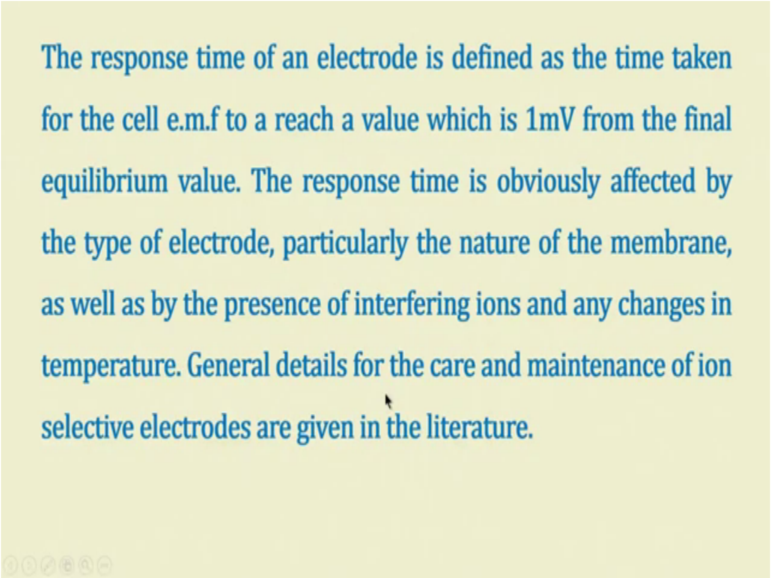

The response time of an electrode is defined as the time taken for the cell e.m.f to a reach a value which is 1mV from the final equilibrium value. The response time is obviously affected by the type of electrode, particularly the nature of the membrane, as well as by the presence of interfering ions and any changes in temperature. General details for the care and maintenance of ion selective electrodes are given in the literature.

So, the response time of such an electrode is defined as the time taken for the cell e.m.f to reach a value which is 1 milli Volt from the final equilibrium value. So, the response time is; obviously, affected by the type of the electrode and particularly the nature of the membrane, size of the membrane, thickness of the membrane, structure of the membrane and all those parameters that define the characteristics of a membrane.

It is also affected by the presence of interfering ions; obviously, and any changes in temperature also because most of these semiconductors have characteristics which are responsive to changes in the temperature. So, the response time is usually; obviously, affected by the all these things. So, whenever you use any MOSFET electrode the manufacturer will prescribe to you the optimum time for minimum time for measure measurement.

Sometimes the digital meter or digital interface of through which we read the numbers screen the digital screen is programmed to become active after a particular lapse of time maybe 5 seconds, 2 seconds, 2 minutes something like that.

So, the instruction will say connect all these things put your sample measure the absorbance after 2 days sorry after 2 minutes. You can say measure the you will get the reading after you wait for 2 minutes you will get the reading and so that is the whole idea is this MOSFET takes a little time for getting into equilibrium state. General details of the care and maintenance of such electrodes are usually given in the literature this is what I was trying to tell you.

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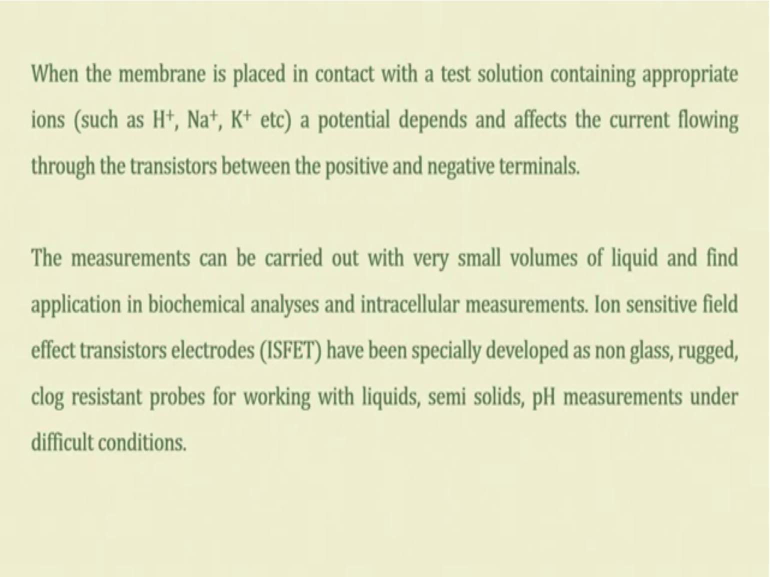

When the membrane is placed in contact with a test solution containing appropriate ions (such as H^+, Na^+, K^+ etc) a potential depends and affects the current flowing through the transistors between the positive and negative terminals.

The measurements can be carried out with very small volumes of liquid and find application in biochemical analyses and intracellular measurements. Ion sensitive field effect transistors electrodes (ISFET) have been specially developed as non glass, rugged, clog resistant probes for working with liquids, semi solids, pH measurements under difficult conditions.

So, when the membrane is placed in contact with a test solution containing appropriate ions whatever we want to determine that is; hydrogen, Na plus, K plus etcetera a potential develops and affects the current flowing through the transistors between the positive and negative terminals.

The measurements can be carried out with very small volumes of liquid and find application in biochemical analysis and intracellular measurements, this intracellular measurement means basically you can put the electrode inside a human body, you want to measure spinal fluid you just make a hole here at the back insert it and see what are the changes possible such intracellular measurements can be made with MOSFETS.

And Ion Sensitive Field Effect Transistors these are known as a ISFET Ion Sensitive Field Effect Transistors electrodes have been specially developed for such purposes they have been developed as non glass. We do not want foreign material to be inserted which is not compatible with our blood tissues etcetera. So, it should preferably be non glass because if the glass breaks there will be glass pieces hanging around inside the body which can cause problems. And they should be rugged and clog resistant such probes are required for working with liquids, semi solids p and pH measurements under difficult conditions.

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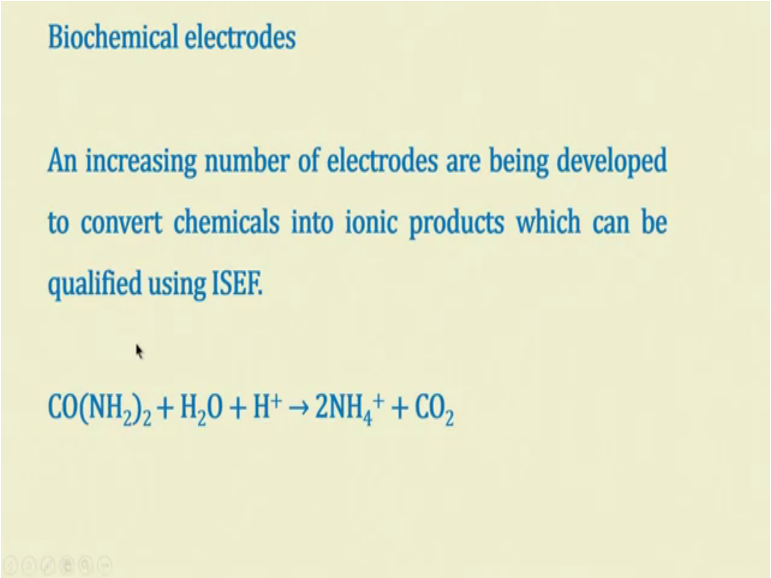

Biochemical electrodes

An increasing number of electrodes are being developed to convert chemicals into ionic products which can be qualified using ISEF.

$$CO(NH_2)_2 + H_2O + H^+ \rightarrow 2NH_4^+ + CO_2$$

So, ISFET and MOSFETS are one of the recent innovations in the ion selective electrodes. Biochemical in the electrodes are another set of electrodes basically, they are all ISEF an increasing number of electrodes are being developed for such things the what they do is to convert chemical into ionic chemicals into ionic products, which can be classic quantified using ISEF. For example, look at this equation CO NH 2 twice H 2 O and water these are all water is available in our body 94 percent.

So, water wherever we want to deal anywhere in the body water will be a an essential component. So, CO NH 2 twice this is the ion and this is H plus in presence of acid ammonia will be released and that will give you ammonium ion plus C O 2 carbon dioxide.

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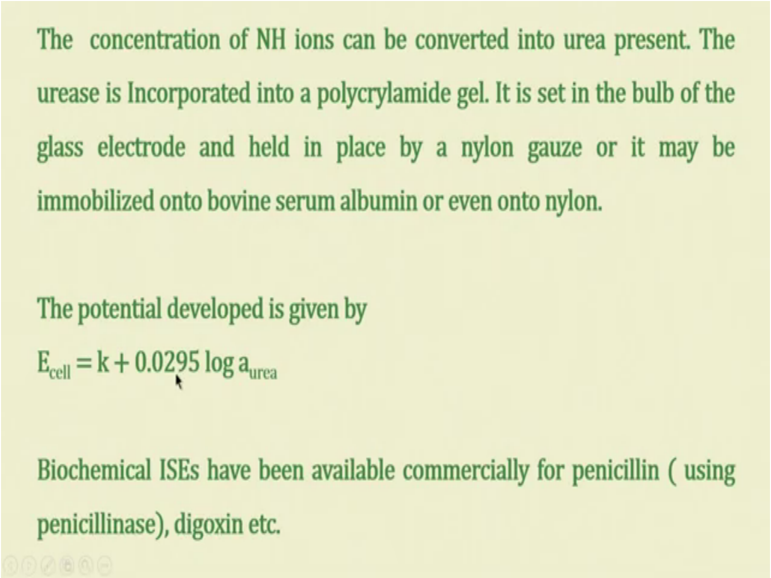

The concentration of NH ions can be converted into urea present. The urease is Incorporated into a polycrylamide gel. It is set in the bulb of the glass electrode and held in place by a nylon gauze or it may be immobilized onto bovine serum albumin or even onto nylon.

The potential developed is given by

$E_{cell} = k + 0.0295 \log a_{urea}$

Biochemical ISEs have been available commercially for penicillin (using penicillinase), digoxin etc.

Those that is not cobalt that is carbon CO urea so, the concentration of a NH 4 NH ions can be converted into urea present because here we are going to measure NH 4 plus as a response that be converted into urea CO NH 2 twice is urea NH 2 CO NH 2 that is how I remember yeah the formula many people remember as CO NH 2 twice or I prefer NH 2 CO NH 2 that also tells me about the structure of urea.

So, if urea is there acidity acidic material is there and then ammonium ions released carbon dioxide is generated and the concentration of ammonium ions can be converted into urea present the urease is an enzyme that is; does this job of converting urea into ammonium ions.

The urease is incorporated into a polyacrylamide gel. It is set in the bulb of the glass electrode and held in place by a nylon gauze or it may be immobilized onto bovine serum albumin or even on to nylon. So, bovine serum albumin when you hate it forms a sort of membrane nylon also we can use we can use nylon membrane any other membrane which will act as a support. So, the potential developed is given by E cell is equal to k plus 0.0295 log of activity of the urea. So, biochemical ISEs have been available commercially for penicillin digoxin etcetera.

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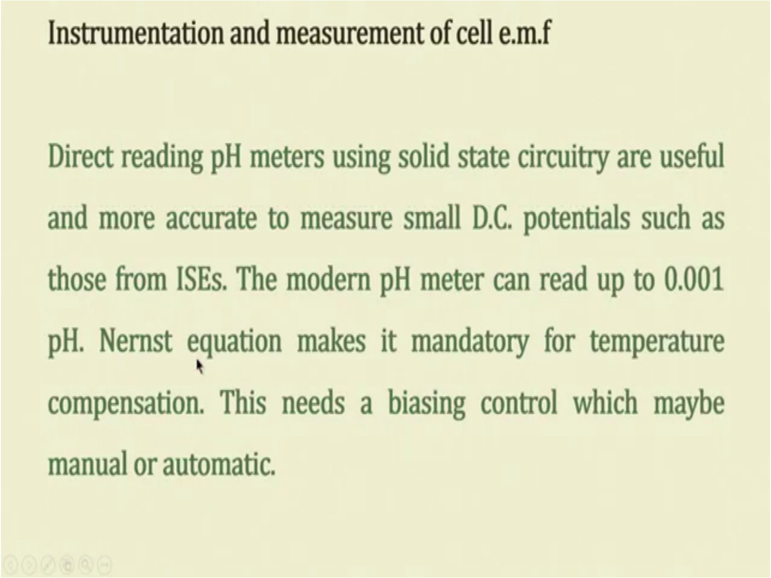

Instrumentation and measurement of cell e.m.f

Direct reading pH meters using solid state circuitry are useful and more accurate to measure small D.C. potentials such as those from ISEs. The modern pH meter can read up to 0.001 pH. Nernst equation makes it mandatory for temperature compensation. This needs a biasing control which maybe manual or automatic.

So, let us discuss a little bit about the instrumentation and measurement of cell e.mf this cell can be either pH meter or ISE Ion Selective Electrode meter basically, operation of all will be essentially same. So, direct reading pH meters are available using solid state circuitry, they are useful and more accurate to measure small D.C. potential such as those from ISEs the modern pH meter can read up to 0.001 pH that is; a fantastic.

Nernst equation makes it mandatory for temperature compensation because, if you are want to you if your accuracy required is 0.001 pH, obviously it will be a function of temperature the Nernst equation know RT by nF RT by nF l NH plus. So, t a temperature has got a direct effect on the quality of the pH determination accuracy of pH determination. So, we want to make it a temperature whatever temperature we measure we need to compensate for the temperature difference from the normal measurement systems.

So, this needs a biasing control which is something to do with electronics and electronics people if you tell them that you need a biasing control for temperature correction they will do it for you. And I am not going into details how such a circuit can be made or how what sort of components go into that will be part of electronics who will if you are studying electronics you will be knowing about such things, but such things should be available in the market shelf.

So, all you got to do is buy that chip and then fix it into the into the meter pH meter. So, the biasing control will be there. So, whatever is the temperature suppose room temperature is 25 and today's temperature is 30. So, you can make the compensation for by using a turning a knob.

And then it can be manual or it can be automated also there nothing very special about adjusting the a knob using correct temperature and calibration nowadays these things are done automatically and it makes lot of sense. So, some instruments include a slope control. So, what is a slope control? If a meter is calibrated around pH 4 a measurement of 9 would introduce some sort of error. This I have already told you is not it. So, in the alkaline range the error can be as much as 1 unit around pH 12.

So, the what we need to do every time I want to standardize a pH meter I need to use a buffer. So, what is the buffer, what should be the pH of the buffer which we want to use for standardization?

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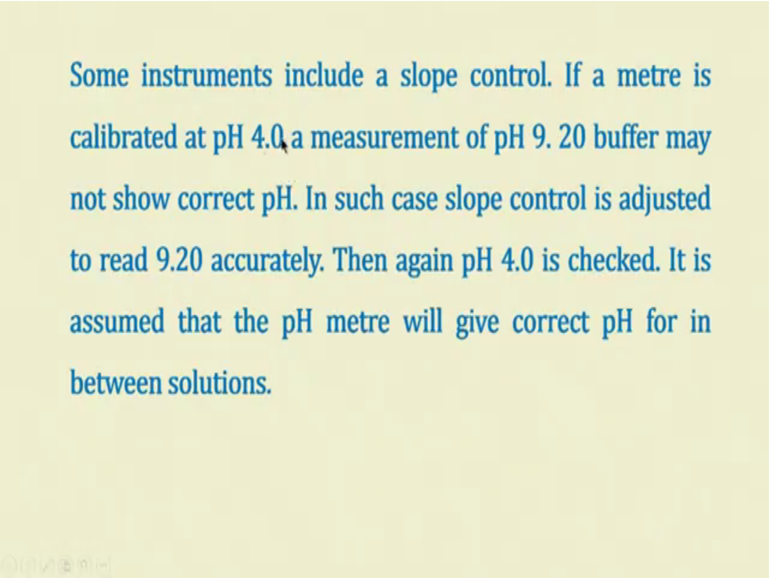

Some instruments include a slope control. If a metre is calibrated at pH 4.0 a measurement of pH 9. 20 buffer may not show correct pH. In such case slope control is adjusted to read 9.20 accurately. Then again pH 4.0 is checked. It is assumed that the pH metre will give correct pH for in between solutions.

We need to use a pH 4 buffer that is a potassium tartrate a phthalate potassium hydrogen phthalate is a standard material, even that potassium hydrogen phthalate that is available in the market as small tablets which you can dissolve it in 100 ml use it as a buffer standard buffer.

So, we use a calibrated buffer at pH 4 and then I want to measure a pH around 9.2. We know that it will not show the correct pH. So, in such case what do? You do we have to adjust slope to RT by nF, what is RT by nF? R is gas constant, T is temperature, n is number of electrons and F is Faraday. So, whatever number you get that should be the slope.

So, if I adjust the slope to RT by n F value that is; then it is adjusted in such a way that a pH of 9.2 buffer should be read correctly as 9.2; that means, 9.20 means 9.20 here also it must read 9.20 not 9.3 or 9.4 or 9.1, but 9.20, I have decided not to write one more 0 here because most of 90 percent of the pH meters are accurate to the second decimal.

I am rounding it off. So, 9.20 would be should be read as 9.20 only in such case, slope control is adjusted to I read 9.20 accurately then again pH 4 I have to wash it change the solution from 9.2 to remove it, wash the electrode 3 times, 4 times, 5 times, 10 times because its buffer. So, buffer buffer will not change after one wash the pH of the buffer will not change after one wash.

So, it will you have to wash it number of times dry it using a tissue paper not an ordinary paper or filter paper that will leave scratches on the membrane. So, such things should be avoided you have to just pat it dry using tissue paper. So, wash it 4-5 times pat it dry with a tissue paper, throw the filter paper, again wash it and then put pH 4 buffer and then assume that, the pH 4 if you adjust it like that; if it gives shows pH 4 again you are ready for measurement of the pH in between solutions.

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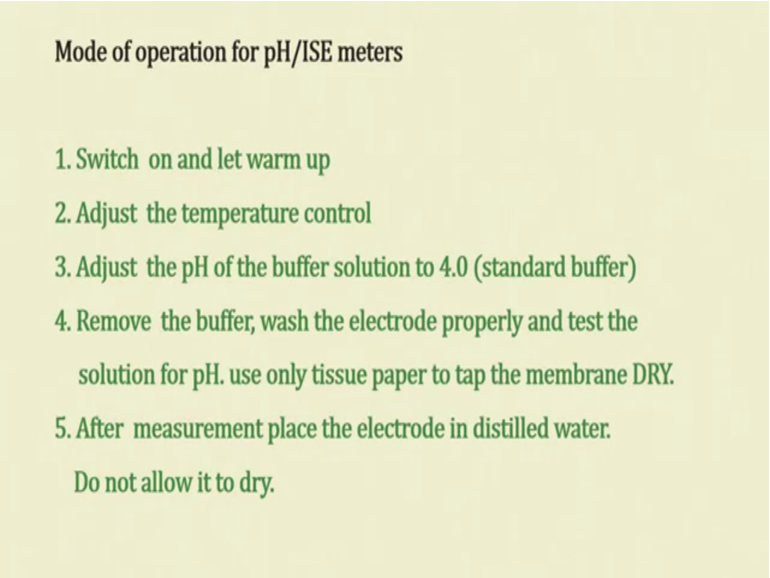

Mode of operation for pH/ISE meters

1. Switch on and let warm up
2. Adjust the temperature control
3. Adjust the pH of the buffer solution to 4.0 (standard buffer)
4. Remove the buffer, wash the electrode properly and test the solution for pH. use only tissue paper to tap the membrane DRY.
5. After measurement place the electrode in distilled water. Do not allow it to dry.

So, what is the mode of operation for pH and ISE meters very simple all you got to do is switch it on and let it warm up. Normally in 90 percent of the laboratories what happens is we come to the laboratory put the machine on and whole day it will be on as long as we are working only when we go up, go home we switch it off and then go. It does not require lot of current or any other care except that we had to make sure that the water should be it the electrode must be in contact with the water all the time.

So, whenever you want to measure you just have to remove that water put your sample solution and check. So, we standardize the pH meter once in the morning and maybe in between if necessary otherwise next day morning. You can do that many people do it once in a week or something that way also possible.

And usually when we have buffer the life of a buffer can extend up to 6 months sometimes the buffer will develop fungus. So, you will have to just filter it and use it use the buffer regularly. So, all those things are part of the instructions and instruction manuals will tell you how to take care of buffer, how to standardize and all those details.

Here I am giving you only a bird's eye view of the maintenance of ISE meters or buffer meters. I have seen in many engineering colleges and even arts and science colleges people do not know how to take care of the electrodes 99 percent of the time whenever I visited colleges and they show sir this is our pH meter I always see that the pH meter is dry and if the pH meter is dry you will never get a proper reading out of that.

And same thing goes through with ion selective electrode also. So, if you take care of the machine, machine will take care of you. So, that is why I am writing this slide especially for your benefit, if you are part of the teaching faculty or part of the laboratory. Make sure, that your laboratory if it has a pH meter or ion selective electrode keeps it properly so that every time you are ready to use it should be available. If the pH electrode is dry then there the ion exchange capacity will go down and you may never get the correct pH.

So, we always advice, always keep this electrode in the in a solution in a beaker, dipped in a beaker come and top it up once in 2 days, once in 3 days make sure that the water does not dry in that beaker. And electrode also should not dry in the beaker. Sometimes what happens is if the for some reason electrode is dried and you are not able to use it we dip it in HCL solution of about one molar solution and then keep it for a day or 2 and then try it.

If it does not work you have no other go except to throw it out and buy another electrode ok. So, getting back to the slide the normal procedure for operation of a ion selective electrode is switch it on and let it warm up, adjust the temperature control of the day and maybe a (Refer Time: 21:03) in India everywhere approximately 25 degree centigrade should be ideal maybe 30 27 is also 27 is average in India adjust the pH of the after putting the temperature control you have to adjust the buffer pH of the buffer solution to 4 and adjust the meter to read the pH 4.

Then you can remove the buffer wash the electrode properly like what I have described earlier and then test the solution for pH use only tissue paper to tap the membrane dry and then after measurement place the electrode in distilled water and do not allow it to dry again.

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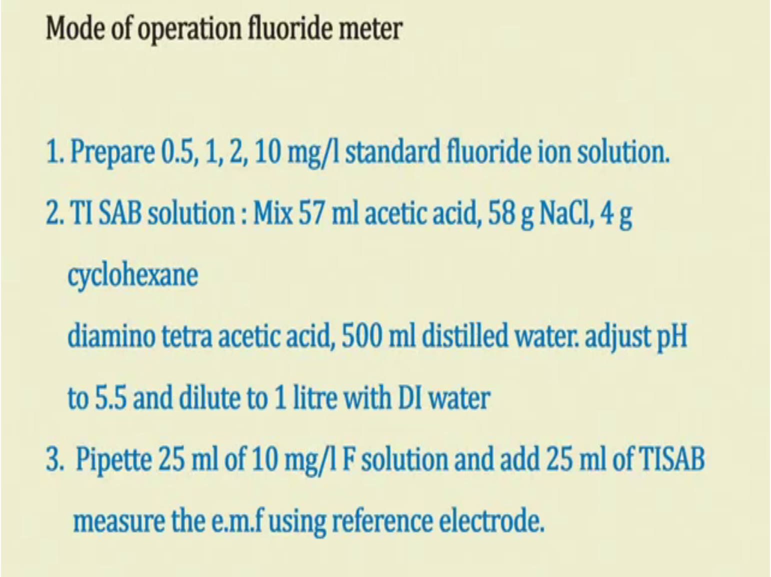

Mode of operation fluoride meter

1. Prepare 0.5, 1, 2, 10 mg/l standard fluoride ion solution.
2. TI SAB solution : Mix 57 ml acetic acid, 58 g NaCl, 4 g cyclohexane diamino tetra acetic acid, 500 ml distilled water. adjust pH to 5.5 and dilute to 1 litre with DI water
3. Pipette 25 ml of 10 mg/l F solution and add 25 ml of TISAB measure the e.m.f using reference electrode.

So, how do I operate a fluoride meter essentially same thing here, what do we do? Is prepare 0.5, 1, 2, 10 milligram per litre of standard fluoride ion solution. You open any textbook they will describe to you what salt of fluoride you should use and where it is available and what should be the quantity dissolved and how to make that solution? So, I assume that you all know such things and then.

So, now, I am putting it as a first sentence prepare 0.5 ppm that is milligram per litre and then 1 milligram per litre this is double and then 1 to 2 again 100 percent double and 2 to 10 500 times double you know 500 times is not it? 2 to 10 5 times So, 10 milli 5 to upto 10 milligram from 0.5 to 10 milligram per 10 ppm you can use prepare standards fluoride ion solutions.

Then what else you need? You need a TI SAB solution it is nothing, but cyclohexane diamino tetra acetic acid. So, you have to mix 57 milliliter of acetic acid, 58 grams of sodium chloride, 4 grams of cyclohexane tetra amino diamine tetra acetic acid and then 500 ml of distilled water you have to adjust the pH to 5.5 and dilute to 1 litre with de-ionised water. We do not want any ionic strength to be changed whenever we want to prepare such samples. So, we use only DI water for dilutions.

Then we can pipette out 10 milligram per litre of fluoride solution add 25 ml of TISAB solution measure the e.m.f using reference electrode. Reference electrode is usually is available or you can buy one or it is incorporated in the fluoride meter itself.

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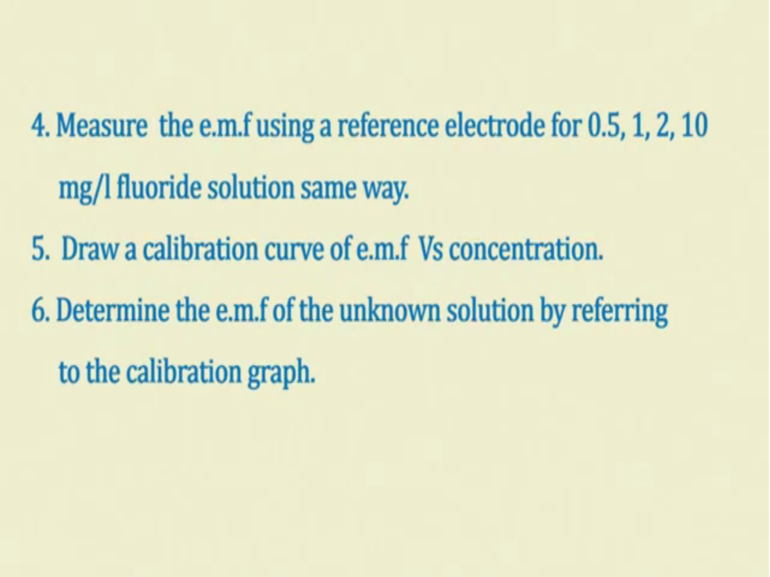

4. Measure the e.m.f using a reference electrode for 0.5, 1, 2, 10 mg/l fluoride solution same way.
5. Draw a calibration curve of e.m.f Vs concentration.
6. Determine the e.m.f of the unknown solution by referring to the calibration graph.

Then we have to all you have to do is press the button measure the e.m.f using a reference electrode for all the standards note down the reading whatever it comes draw a calibration curve.

Whereas of e.m.f versus concentration and determine the concentration of the unknown. In modern gadgets what do they do is they restore the calibration curve in the memory assume that; assuming that; all other parameters are constant then if everything is stored. All you have to do when you go on a field test is you just take the sample dip your fluoride meter, simply read the concentration, it will measure the e.m.f, refer it to the calibration curve, stored in the memory and it will display the concentration directly onto the display screen.

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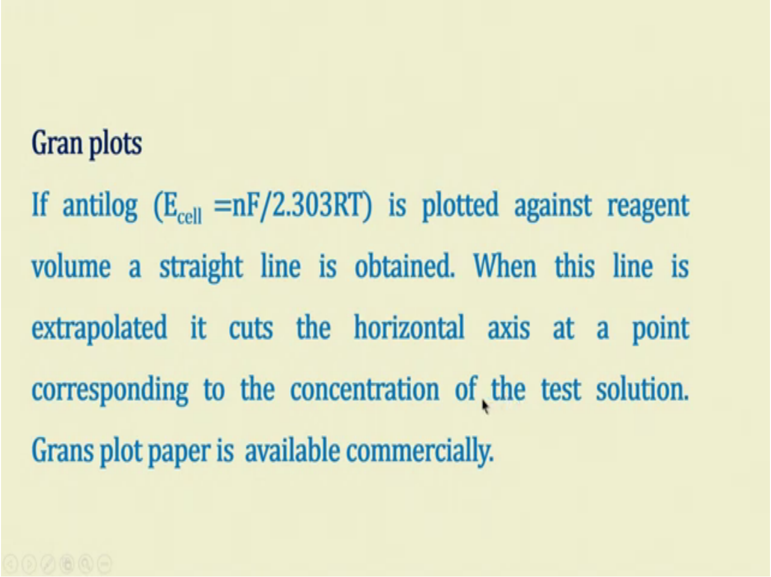

Gran plots

If antilog (E_{cell} =nF/2.303RT) is plotted against reagent volume a straight line is obtained. When this line is extrapolated it cuts the horizontal axis at a point corresponding to the concentration of the test solution. Grans plot paper is available commercially.

So, now I want to describe to you what is a Gran plot a Gran plot is a very simple system or measurement you have measuring the RT by nF value that is the slope usually we say RT by nF 2.303 RT by nF is the slope of the electrode in contact with a solution when you make the calibration curve.

But if antilog of this quantity nF divided by 2.303 this is the sort of RT by this is not RT by nF this is nF by 2.303 RT 1 over RT is plotted against reagent volume we should get a straight line this is a very simple concept. So, when this line is extrapolated it cuts the horizontal axis at a point corresponding to the concentration of the test solution. So, Gran plots papers are available commercially because you have to plot the anti log value of nF by 2.303 RT.

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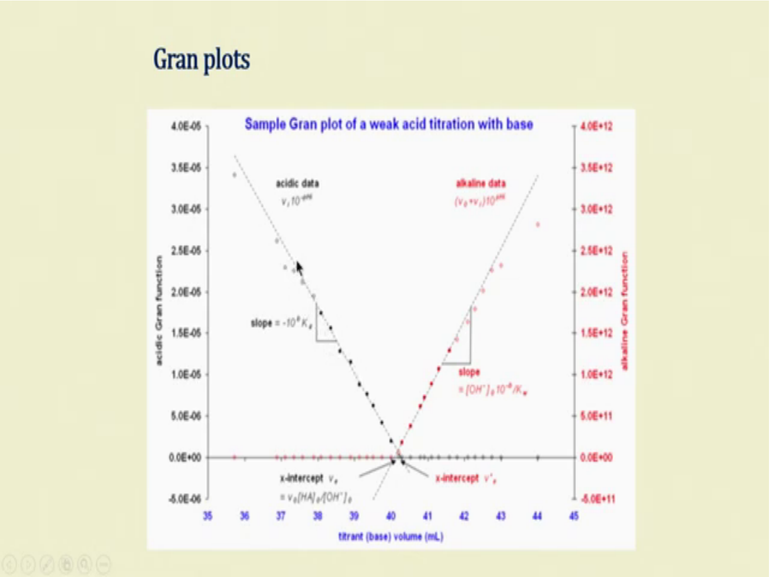

Gran plots

So, here is a Gran plot for you and here on the x axis we have a titrant base volume in mL and then this is the x-intercept and the Gran plots are here now RT by nF values anti logs and this is in acidic medium see how beautifully the whole series of points are connected. So, here it is acidic Gran function on the left side and with the red one we have the alkaline Gran plots.

So, the slope of the alkaline solution is minus OH minus then 10 raised to minus b by Kw and this is the other one the here is the potential on both sides. And the intercept is the concentration of the substance that is volume. So, such Gran plots if you refer to any research papers based on ion selective electrodes or the pH metal ion electrodes you will come across several such a the presentations where they refer to Gran plots do not get confused it is only the slope anti log of the slope plotted against reagent added. So, it is easy to handle the signal that is right.

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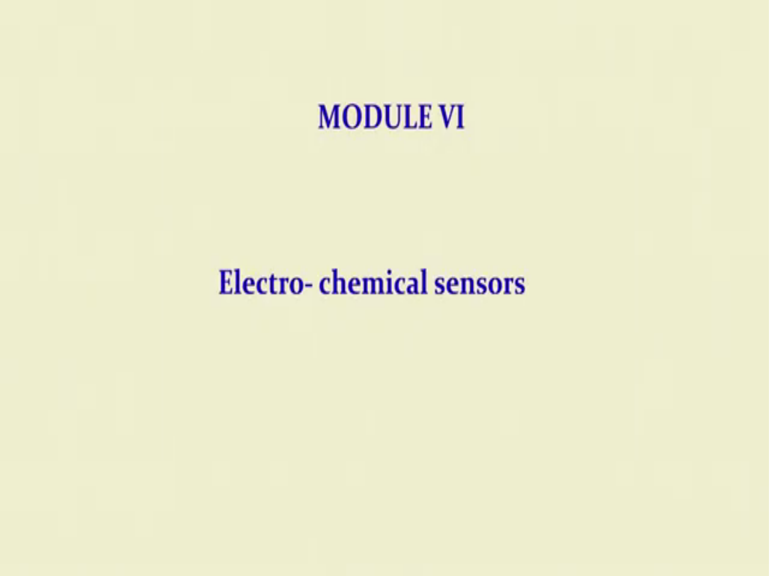

MODULE VI

Electro- chemical sensors

So, here we complete our discussion on the ion selective electrodes and we go into another concept of the electro chemical technology that is; the electro chemical sensors slowly we are moving from basic electro chemical technology of measurement of voltage, current etcetera onto this potentiometry, precipitation reactions, redox reactions, palaeography, conductometry and then Karl Fischer titrations, ion selective electrodes now we are moving into the world of sensors. So, after this we will be dealing with the process of lens and other things.

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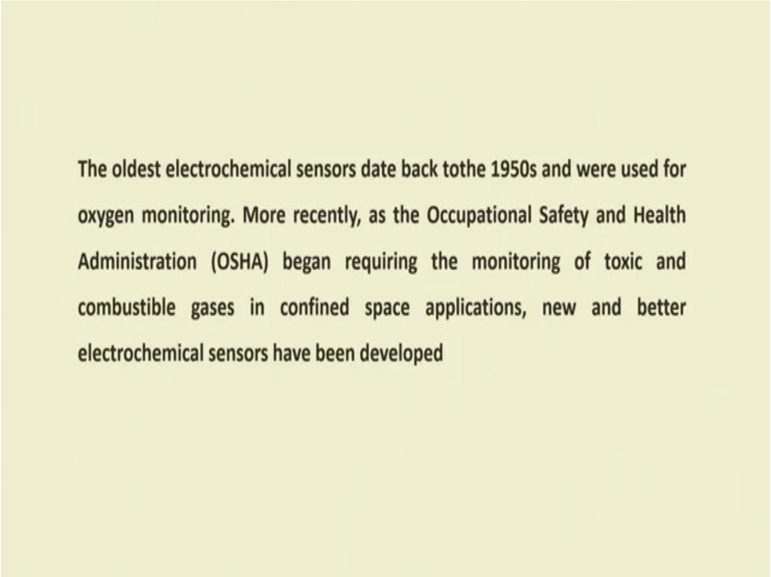

The oldest electrochemical sensors date back tothe 1950s and were used for oxygen monitoring. More recently, as the Occupational Safety and Health Administration (OSHA) began requiring the monitoring of toxic and combustible gases in confined space applications, new and better electrochemical sensors have been developed

And the electro chemical sensors I have to tell you that the oldest chemical electro chemical sensors date back to 1950's almost 70 years before they were already there and they will used for oxygen monitoring.

I had described to you the oxygen membranes as those things were being measured even around 1950's more recently the OSHA Occupational Safety and Health Administration began requiring the monitoring of toxic and combustible gases in confined space applications and new and better electro chemical sensors have been developed. This is very important because confined spaces there is always a danger of someone getting confused.

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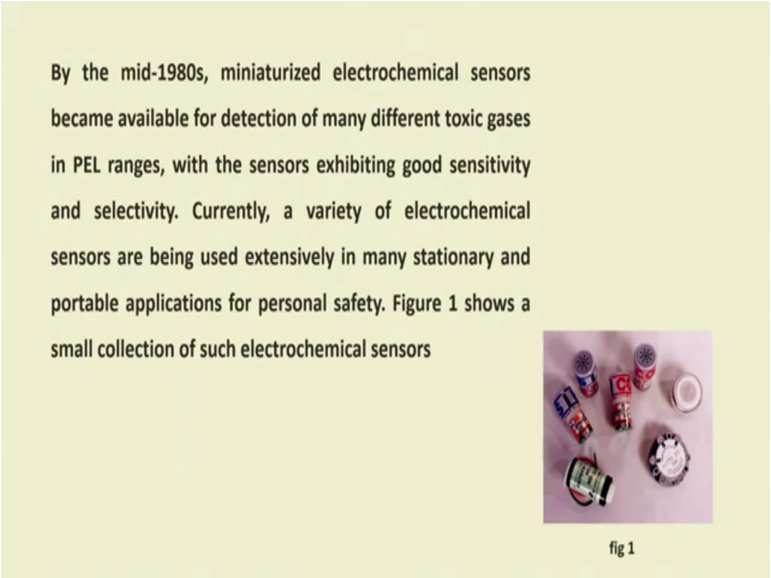

By the mid-1980s, miniaturized electrochemical sensors became available for detection of many different toxic gases in PEL ranges, with the sensors exhibiting good sensitivity and selectivity. Currently, a variety of electrochemical sensors are being used extensively in many stationary and portable applications for personal safety. Figure 1 shows a small collection of such electrochemical sensors

fig 1

Someone getting hurt if there is not enough oxygen for example, if a sever or something is to be repaired a person goes down the sever there is no oxygen lot of hydrogen sulphide will be there he will suffocate and die. Such things we will keep on seeing in the newspapers all the time. So, we also come across situations where a person is confined in a particular place especially mines in a very confined space they keep on working. And the oxygen level needs to be monitored very regularly whenever combustion is taking place we want to measure the, what is the oxygen available for combustion, because oxygen is the most for combustion treatment.

So, by the mid- 80’s miniaturized electro chemical sensors became available. It is not very far you know we were all a students at that time and then they were all new gadgets, exciting gadgets for measurement and many of our colleagues were working on the electro chemical sensors at that time in R and D laboratories. And we were all witness to developments exciting developments in the world of miniaturization as well as electro chemical sensors world.

Nowadays, it is a world of sensor because wherever any monitoring is to be done we say why do not you put a sensor there you want to measure the temperature in the above the surface of the earth 20 kilometers above the earth we say put a balloon, put a sensor there in the balloon. So, switch it on when it goes through 20 kilometers. So, you want to measure, how much is paroxysmal nitrate in the stratosphere put some simply a balloon send the balloon there and then switch it on and then measure the altitude, measure the altitude, measure the sample paroxysmal nitrate like that; 1000 of sensors for various chemical entities have been developed.

They are available in the market and there were not many made in India in that concept in that aspect Indian India is an underdeveloped country anyway, as far as technology is concerned and many of the detection for toxic gases you will know they are not available in India.

Recently I wanted to measure the sulphur dioxide and then VOC Volatile Organic Carbons in an environment about 300 meters above the earth coming from a stack, but there were no Indian equipments available for the form a monitoring such VOCs. What is a VOC? VOC is a Volatile Organic Carbon, many of the organic carbons, many of the organic solvents below the boiling point of 350 degrees are referred to as VOCs 90 percent of the petrochemical combustion gases would be VOCs.

And any solvent is a VOC among the VOC there are methane based and non-methane based. Non-methane based would be aromatic solvents and maybe aliphatic solvents also, but those based on methane CHCL3 CH 3 CL and then CH 2 CL 2 like that; they are all ozone damaging compounds. So, in general VOCs are classified as a methane and non-methane VOCs. I found out that when I wanted to measure organic solvents like methanol acetone (Refer Time: 35:11) and then ketones not 1 electro chemical sensor was available for measuring their concentration at high altitude.

So, anyway, but such things are available in the market there are people who will import them and sell it to you and the detection for many different toxic gases in PEL ranges with the sensors exhibiting good sensitivity and selectivity. So, miniaturized sensors are available and they would be I have shown them here. So, the sensor you can see the sensors here very small sensors maybe about 5 centimeter and this could be about to 10 centimeter here these are all 2 centimeter etcetera etcetera.

And such sensors are available very easy to fit in electro chemical circuitry and they can show you they can show you the data on a display screen in a wherever you are sitting at a long or some other distance. So, it is like having a camera for a detective camera in a particular place there. So, it will be a detective sensor for particular specific chemicals and a variety of chemicals electro chemical sensors became available for the detection of toxic gases. And then with sensors exhibiting good sensitivity and selectivity currently a variety of electro chemical sensors are being used extensively in many stationary and portable applications.

For personal safety you can even carry a sensor in your pocket and you can carry many of the sensors on your body for example, I am carrying a micro microphone here, but I can carry you can see my pen here I can instead of the pen it can be a sensor. If I am a mine worker I can put it here and go down the sensor will catch all the radiations coming from the earth and there are a lot of radiations called something like radons.

And the radioactive material I can pick it up and then if the radioactive component from my in my body goes up I will be put out of action for some time until the radiation level comes down. So, it is important to measure not only the physical parameters such as this temperature pressure if the working places and then radiation levels and then oxygen level, nitrogen carbon monoxide level and all those things.

Where people would like to would be terribly afraid of carbon monoxide and carbon dioxide also. So, where ever there are fire chances carbon monoxide and carbon dioxide sensors are required.

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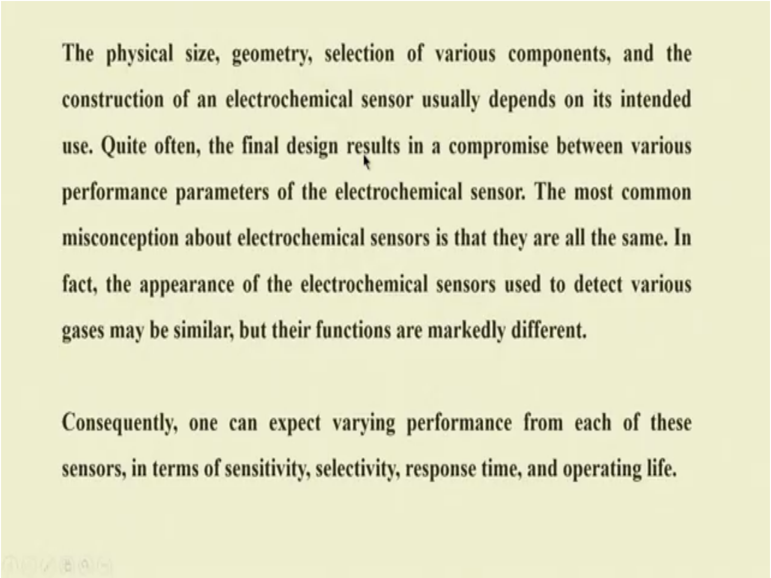

The physical size, geometry, selection of various components, and the construction of an electrochemical sensor usually depends on its intended use. Quite often, the final design results in a compromise between various performance parameters of the electrochemical sensor. The most common misconception about electrochemical sensors is that they are all the same. In fact, the appearance of the electrochemical sensors used to detect various gases may be similar, but their functions are markedly different.

Consequently, one can expect varying performance from each of these sensors, in terms of sensitivity, selectivity, response time, and operating life.

So, the physical size and geometry and selection of the various components and construction of an electro chemical sensor usually depend on its intended use. We will continue our studies on the sensors in the next class probably we I will explain to you more about their functions.

We will not go into details of the manufacturing because basically most of them would be based on a electro chemical sensors like membranes and other things which I have already discussed in the previous class that is ion selective electrode.

Thank you very much.