Design Practice - 2
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Lecture - 13
Introduction to Sensors

Hello and welcome to this Design Practice 2 module 13. We were talking about sensors and we were talking about the sensorial model of an analyte being investigated through a recognition element which is generally immobilized on the surface of a otherwise constructed detector.

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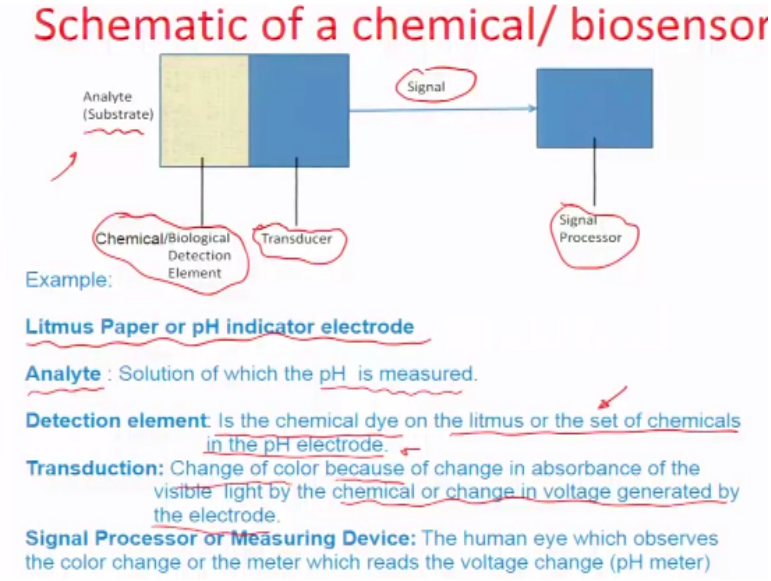

Detector typically does a transduction in terms of the chemical signal being converted into another machine readable signal which can be electrical or optical and the signals are sent in to a signal processor which is able to interpret based on the nature of the signal and that way one can understand the analyte better in terms of its chemical or molecular composition. I explained this how a litmus paper or a pH indicator can serve as a sensor.

Because almost all the components which are there in the sensing model come in for example there is an analyte, the analyte in this case is a solution of which the pH needs to be measured. So we are referring to hydrogen ions as the principle analyte in the solution which you are looking for. For this there has to be a detection element. In this particular case it is a chemical dye on the litmus paper which changes color as it touches and mixes with the hydrogen ions.

So that is basically the recognition element and obviously there is a change of color which is actually giving a transduction scheme so the color paper itself, the pH paper or the litmus paper itself is the body which does that transduction in terms of a change of color from the existing color dye to that what happen when the color reacts with hydrogen plus or protons and this colorimetric detection is then you know visibly sensed by our eye.

So the signal goes to the brain and the brain is able to see whether there is a color change or supposing you wanted to electrically record then there can be some kind of an electrode which measures the hydrogen plus concentration in the solution through some kind of a equilibrium chemistry and it basically transduces in terms of a few electrons being transferred either released or taken up so that those electrons or the variation in the flow of the electrons may give you an idea of what is the voltage which is generated by the analyte is brought in the near vicinity of the particular sensor.

So the signal processor can be the human eye in case of the litmus paper or in case of a pH inductor it can be a electronic module which will do all the signal processing. So let us now look into the various sensors that even human beings are blessed with for example the nose and the eyes you know and how effectively this works in the sensorial model. In fact all the senses that we have works on that principle of detecting an analyte through a transduction process to giving signal on the brain which would give you an idea about what we are sensing or how much we are sensing.

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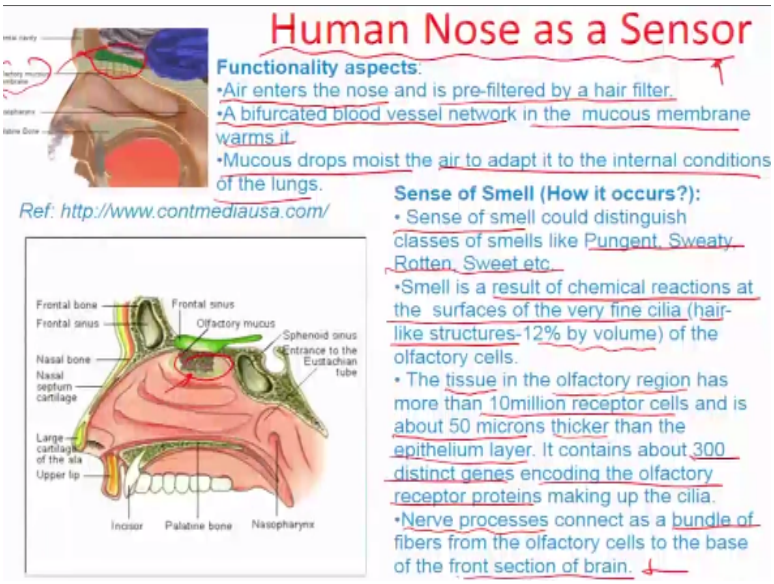

So the first aspect that I would like to describe here is the human nose. So human nose is an excellent sensor. Functionality wise if you look at the different aspects of the human nose you know air enters the nose. It is prefiltered by a air filter which kind of removes all the foreign particles before conditioning the air for the internal purpose you know within our human body.

So the bifurcated blood vessel networks particularly present in the mucous membrane which is very you know it is just on the it is placed somewhere around the air tract this particular olfactory mucous membrane as you can see here is in the nasal passage and what the mucous membrane does is that it basically moistens and conditions the air to adopt to the internal conditions of the lungs and so there is pre-filtration followed by a moistening.

And then the here the air finally enters into the nasal tract into the lungs and you know you get different senses, sense of smell for example. So humans can particularly distinguish between smells which can be pungent, sweaty, rotten, sweet etc. So what exactly is going on in terms of the sensorial you know picture, what is the transduction effect if we want to look at that we see that smell is the result of chemical reactions at the surface of this very fine hair-like structure.

Which are otherwise known as cilia which are present in the olfactory mucous membrane on its surface and they occupy around 12% by volume of the surface. They are so densely populated on the surface of this olfactory membrane and so therefore such hair-like cilia which are there have

thousands of chemical reactions going on. If we looked at particularly the tissue which you know is used to make up of this olfactory region it has more than 10 million receptor cells.

And the tissue is physically about 50 microns thicker than the epithelium layer containing about 300 different genes which can encode the olfactory receptor proteins on the hair-like cilia and this continuous encoding of different genes resulting in a generation of a you know sequence of amino acids from the cilia is what makes the sense of smell come up.

So basically the chemical reactions which would happen on the surface of the cilia would actually be in terms of some charge transfer or charge release which would further go through our nerve processes as a bundle to the front section of the brain and the brain would therefore indicate what kind of smell it is; is it too pungent or too sweaty so on so forth. So there are different aspects.

So it will also having, you know the brain will also be having a sort of a memory where there will be a comparative with the existing signal that is being generated and if supposing the brain is able to map the particular signal to one of those categories then you can actually be able to realize what is pungent and what is sweet. So this is the whole functionality, this complex functionality of this olfactory membrane which is responsible for giving the sense of smell.

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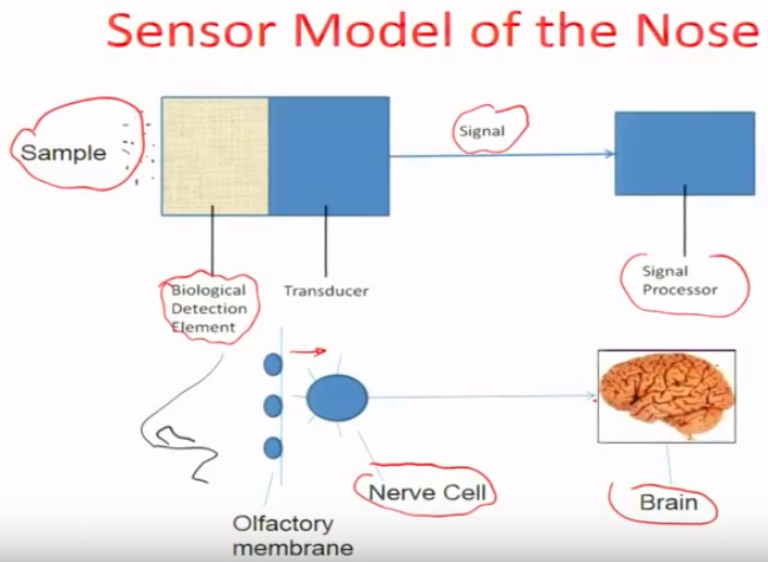

So if I wanted to lay it out as the sensor model again the sample that we are collecting here is the air molecules which are passing through your nasal tract. There is a biological detection element that is the hair-like cilia which is there on the olfactory membrane or which is going to be responsible for the thousands of chemical reactions with the different materials or different gases which enter the nasal tract.

And then transduction is the result of several such electronics changes which would then through a nerve bundle go into the signal processor. In this case brain is the signal processor and the nerve cell which is there is basically responsible for all the charge transport. It is a part of the central nervous system which would be corresponding to certain chemical reactions on the olfactory membrane, okay. So in a way that is how you can lay out the sense of smell.

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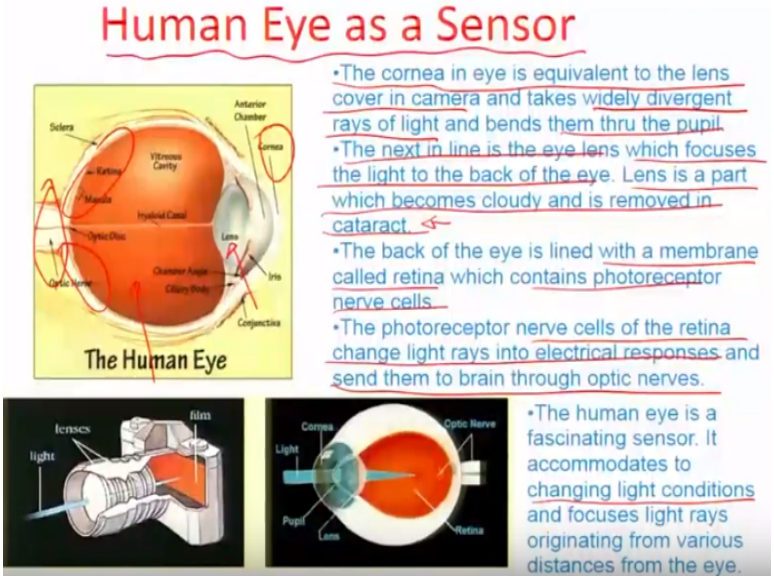

Similarly, if we look at the sense of vision, human eye is a fantastic sensor again based on what the retina senses in terms of light signals and sense the head. So if we looked at the eye there is a cornea in the eye which is equivalent to the lens cover of a camera. Right here you can see the cornea. It takes widely divergent rays of light, bends them through you know the pupil into the retina okay.

So this is the inner cavity of the eye and retina is somewhere at the back side here, the lining here you know for example which has thousands of opsin proteins which would change its nature and form for it to be able to sense. So the next in line is the eye lens which focuses the light to the back of the eye. The lens is the part which becomes cloudy and is removed due to cataract etc.

So therefore there is not much focus if the eye lens goes bad okay or even the intensity gets curtailed and not enough sensation is felt by the retina so that it cannot give signals to the brain anymore okay. So, so this eye lens works as the camera lens focusing the light into the inner chamber of the eyes. The back of the eye is lined with again a membrane called retina I just showed. It contains photoreceptor nerve cells.

These photoreceptor nerve cells on the retina change light rays into electrical responses okay sending them to brain through the optical to the optic nerve. The optic nerve is somewhere here in this particular zone okay. And basically the change in light conditions are automatically again customized to the requirements of the retina because you know there are options to have various you know intensities routed into the eye.

For example if there is a sudden bright light automatically the amount of signal that the eye receives would be shortened because of the eyelids which would then you know close the aperture into a smaller inlet.

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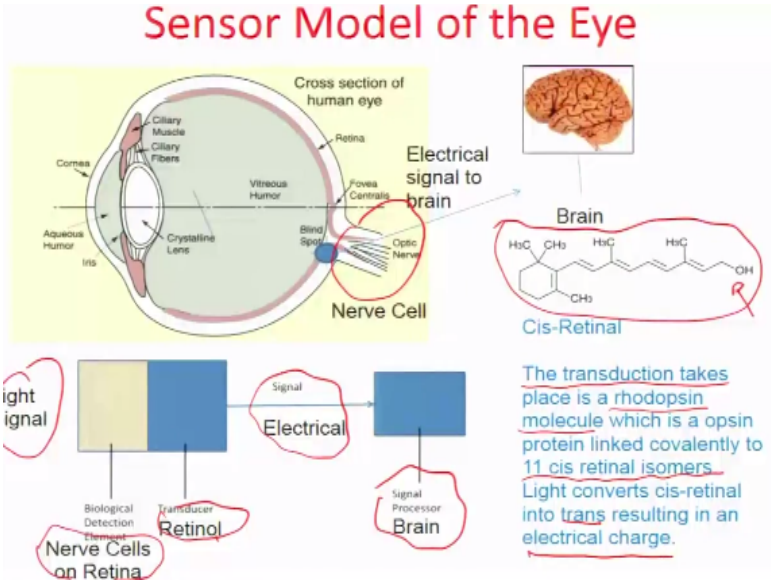

So if I wanted to model this as a sensor basically the transduction that is taking place is a rhodopsin molecule. It is an opsin protein linked covalently to 11 cis retinal isomers. These are the you know the organics, the molecular structure for the cis retinal and you know if supposing a light signal comes and falls on such a such a molecule, such an opsin protein it changes into a trans retinal which actually results in a charge transfer, electrical charge transfer.

So essentially the molecule which is there on the retinal cells changes its form thereby inducing bunch of electrons which again goes through the optic nerve all the way to the brain so here the light signal is the analyte of interest. The nerve cells on the retina formulate the recognition element. Again the retinal molecule which is there, retinal molecule which is there on the as a protein, the opsin protein on the retinal cells. They work as a transducer.

So their change in state results in a bunch of electrons which again are transmitted through as a signal an electrical signal through the you know the optical nerve or optic nerve all the way to the brain which acts as the signal processor in this particular case. So this is the sensorial view of eye. So therefore you are seeing that even in our own human body where there are many such sensor layouts which help us to move forward or control you know our actions etc.

These are all based on the sensor model okay. So therefore from now on any sensor that we discuss or any methodology of sensing we discuss we need to organize it in terms of what is the

analyte what is the recognition element, what is the transduction phenomena or what is the transducer and then what is the signal and what is the signal processor.

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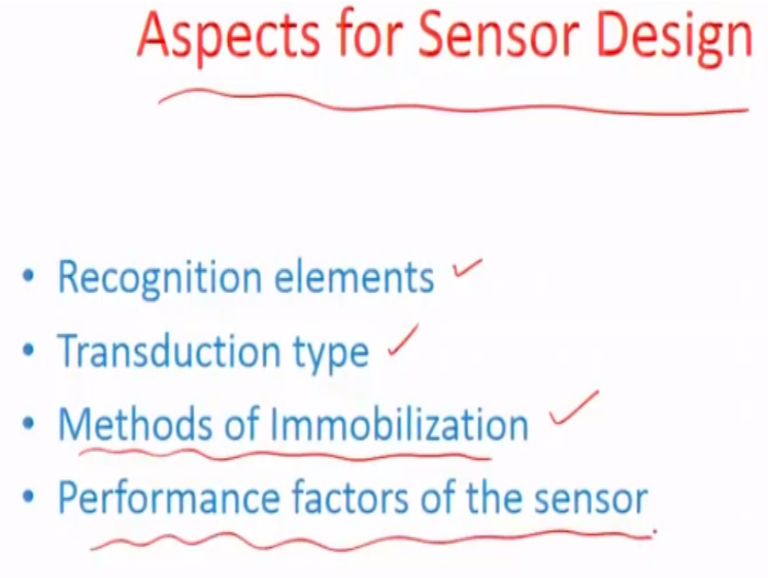

So let us look at this fascinating area of sensors, what are the different aspects that one needs to consider when we talk about the sensor design. So you have recognition element, transduction type. Obviously, there is a question of how the element is being immobilized on to the sensor surface which is going to pick and choose that portion of the analyte which makes sense or you know gives value to whatever is the overall modality of measurement is.

And then there are various aspects like related to performance factors of the sensors etc. So these are the four different aspects in the sensorial design.

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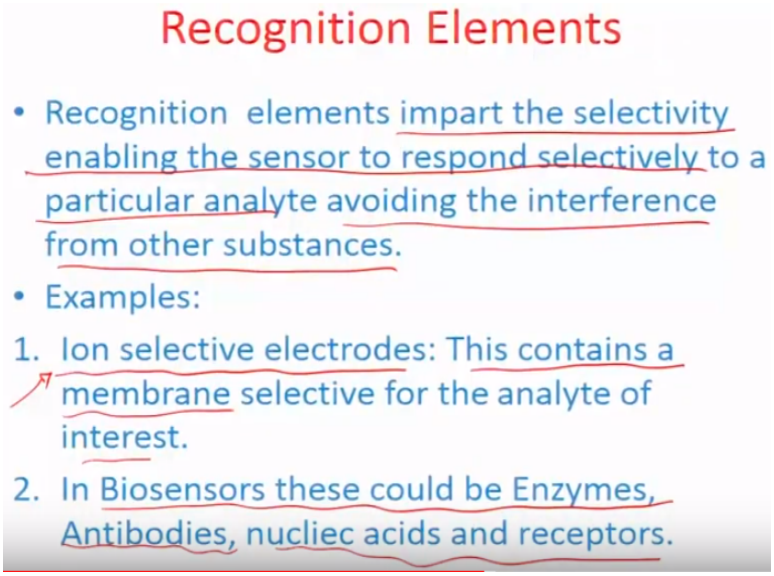

Let us look at it one by one. Recognition element for example imparts the selectivity enabling the senor to respond selectively to a particular analyte avoiding the interference from other sources. Now the analyte maybe a light signal or a gas or even a fluid that we are measuring but what the goal of a signal sensor is to sort of suitably modify the particular you know analyte of interest which maybe present in a mixed or dissolved state from the others.

Okay, so that suitability, that selectivity has to be there of the ability to select the one which we are looking from you know the one which or the many which are available okay in the near vicinity of the element, the recognition element. So examples could be for example ion selective electrodes. These are one of the simplest of the sensors which come in very handy when we talk about pH measurements for example.

So the ion selective electrode may contain a membrane which would be able to selectively gauge on the protons and not a bunch of different ions which are there in the near vicinity. It could be a size based selection. For example it may be as small as it allows only the charge transport of H+ whereas other identical species which are nearby and not having so less a size gets shielded off and are able to prevent from entering the sensorial surface where there is a electron transition which is taking place.

So therefore there is a way of how to immobilize the selectivity material on this electrode so that such a transition can happen. Okay so this can be one example. In biosensors we can talk about enzymes or antibodies which would create or trigger a reaction. For example let us say when we are talking about glucose sensing there is a enzyme which catalyzes glucose into gluconic acid and hydrogen peroxide.

This enzyme is also known as glucose oxidase and so if I wanted to immobilize the surface of a sensor which otherwise is a pH sensor and we should be able to record the you know the gluconic acid which is actually a weak acid in this particular case in terms of the excess hydrogen ion concentration that increases because of its formulation. So wherever on the sensor surface we need to trap glucose, we somehow immobilize the antibody in a manner or the enzyme in a manner so that it goes and selects only the glucose molecule.

And which creates a change in pH only based on catalyzing the glucose molecule. So this could be an excellent example of a bio-recognition element. Several such elements are abundantly available for example when we are trying to look for microorganisms we could have the specific antibody in place which would look for the microorganism of concern. Or if we are having to recognize something related to a gas so maybe a structure which would be having diffusivities in a manner so that the highest diffusivity is that of the target gas.

And there are many others you know other gasses which have stopped from diffusing on to the sensorial surface. So these schemes have to be in mind of a person or sensor designer who works on such a sensor. So this is one aspect, the recognition element. Let us look at you know another aspect which is like how antibodies would formulate a change in the color signal. Let me give you an example of this kind.

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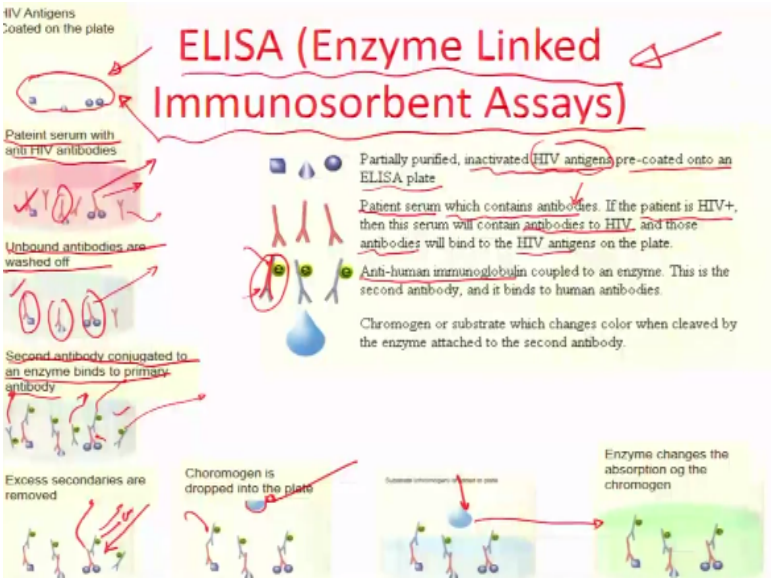

So this is a very famous technique of sensing which is available to clinical diagnostics world which is known as ELISA. It is called enzyme linked immunosorbent Assay and this ELISA testing is very well used in the detection of you know inactivated, the detection of HIV antigens. So what we do here is that we start at step 1 or level 1 here where we are taking the inactivated, partially purified HIV antigens and precoating the surface which would be treated as a sensing plate for the ELISA scheme to happen.

So step 1 shows the coated HIV antigens. HIV of course is the AIDS virus okay or immune virus, human immune virus. So when the patient's serum from which we want to investigate whether there are there is an infection, HIV infection within the patient or not is collected, it contains or it will contain antibodies raised by the natural immune system of an individual against the HIV antigens okay and these antibodies should be able to bind and block some of these antigens from their functionality.

So that is all the idea behind the immune recognition and you know immune response of an individual. So if the patient is being diagnosed for whether he is HIV positive or not and supposing there is an infected patient so his blood will definitely contain antibodies which are grown to the HIV antigen okay and those antibodies will definitely bind to the external HIV antigens which we have put in the ELISA plate from in the step 1 of the particular reaction.

So we put the patient's serum, blood serum which contains these antibodies and let us say he is infected so these antibodies have gone and started binding okay to the patient's serum and you know it binds with the anti-HIV antibody okay which are raised in the patient's blood. So in step 3 we try to see whether the binding is proper, whether the binding is you know of an extent that it is a chemical bond. So we wash off the remaining ones which are absorbing to the plate and not as such absorbing to a site which had a HIV antigen.

So those which are unbound are washed off okay of this particular plate and the ones which are actually bound to the HIV are the ones which are specifically the anti-HIV antibodies, they are being retained and the remaining other components which will be there in the serum are all washed away now and so we have a bound set of antibodies now which are there. And what we do in the fourth step is after washing, a second antibody is conjugated to this enzyme, to an enzyme which is binding to another primary antibody.

So let us say you know we bind this secondary antibody to the long chain of a primary antibody and if we wanted to go into the antibody chemistry we would look at that this antibodies are a Y like structure with two epitope sides on two arms of a Y and a stem which is actually made up of a long chain molecule and these can specifically then bind to some other antihuman immunoglobulin and so therefore we have taken this which we otherwise know as a secondary antibody.

So, so this secondary antibody however in this case is connected to an enzyme, so this is a chemical modification that has happened. So this enzyme is already connected to this secondary antibody which is then bound on the primary antibody which is already immobilized on the plate. So the immobilization chemistry has happened at this step and all the other antibodies have been gotten rid of.

So whatever is staying there or immobilized is already there and to them you are further binding those enzyme linked secondary antibodies which are specifically meant for binding only to the heavy chain portion of the primary antibody which is the anti-HIV antibody, the red one here

okay. So the remaining enzyme coupled secondary antibodies which are unbound in the plate or again washed off so they are gotten rid of and so now you have stacks.

So the stacks are corresponding to those points which had the HIV, which had the HIV antigens bound on the plate and then the primary antibody and the secondary antibody with the enzyme. So this is the stack which is there and the advantage of this stack is that whenever there is a sort of a chromogen which is dropped into the plate as you can see. This is a chromogen which has a certain color. The moment it comes in contact with the enzyme, it changes the color, okay.

So that is how the enzyme is supposed to work on a chromogen by changing this color. So if the antibody which is of primary kind were present in the serum then this chemistry would work and whatever drop of chromogen has been dropped into this particular case like you can see the drop being dropped here would change color then. Let us say there is a blue to green transition which is there.

And in case of color change the primary antibody which was supposed to be there in an infected person was present because of which this stacking and the presence of an enzyme and subsequently the change of color has been initiated throughout this process of ELISA, okay. So having said that this whole recognition element of antibodies you know can be then put on a flat surface with some kind of a color change indicator.

Maybe it can be a spectroscopy driven module which can talk about if there is a infected patient whose serum contains the anti-HIV antibody what is going to be the extent of color change which can then be calibrated to the amount of infection which is present in a sample. So ELISA therefore it can be a standard chemical protocol many steps of which have been scientifically thought out but again can be integrated to such a sensorial outcome, okay.

So these are some of the instances where bio-recognition elements like antibodies etc. are signaled in or factored in for designing the sensors. Obviously, we will be getting into the details in the next few modules of how some of these sensors can be actually realized. Whether it is electrochemical sensor or whether it is you know optical sensor and I would expose you to a

variety of you know cases and research papers where we talk about this in the next few modules. So till then, until then I think I will close this particular module and in the next module we will take up the potentiometric or the electrochemical sensors. Thank you very much.