BioMEMS and Microfluidics
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Lecture – 14

Hello and welcome back to this 14'th lecture.

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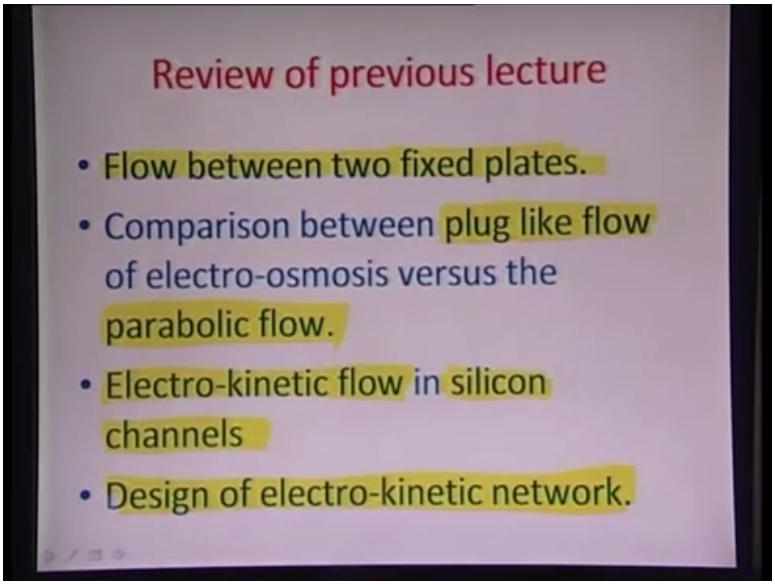

Let us too quick review of what we try to cover last time we try to kind of look into the equations for flow between to fix plates we also compared of the profiles that would be generated the velocity profiles, that would be generated between the different kind of flow electro-kinetic and pressure driven and we found out that for the electro-kinetic flows the flow up files is more like a plug. So, as uniform velocity all through the cross section between the double layers formulated on all the sides of the channel very close to the in the surface of the channel.

So, electro-osmosis, electro-kinetic flows like freezes this essentially has a flow, which is more like a plug as supposed to the pressure driven flow, which is more parabolic in nature. So, there is a velocity variation from the point of no slept on both sides maximizing when you considered the exact center the work center of the channel. We also try to investigate, why or how over is mechanism of the electro-kinetic flows in silicon channels. So, essentially there is a formulation of hydroxide a linkages on the top of the silicon and on contact with certain pH solution with the certain pH it dehydrox it actually formulates with dehydrogenates and forms Si O minus.

Essentially there is a negative charge, which is developed on the top of silicon surface and because of which whenever there is a water or any other consistent flow within the micro channel of almost always there is this diffused layer, which is created in the bulk and as it moves by an external voltage a applied perpendicular to the cross sectional the channel it tries the fluid along with it and essentially goes to one in from other. So, we also how adjust about to discuss the design of electro-kinetic networks in such flow applications and would like to restrict this up little more today.

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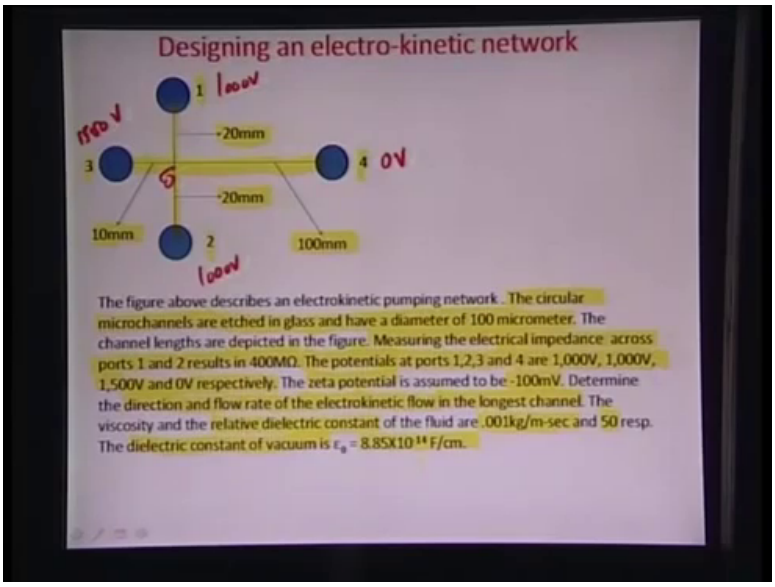

So, the question that we post last time and, which was not time fact solved was that how do we design really such electro-kinetics networks and these networks ((Refer Time: 02:34)) useful for micro pumping micro scale transportation of fluid. So, here in this figure, you as show there is a as you see there is a crisscross architecture of micro channels. And there are 4 reservoirs marked 1, 2, 3 and 4 and length dimensions of this individual channels are given like for example, if you consider the center to be O the center of the intersecting network of channels to be O.

Then, 1 O length is 20 milli meters 2 O is again to 20 milli meters 3 O is above 10 milli meters 4 O is above 100 milli meters. So, we assume that the cross section of these micro channels are perfect circular there rest in glass and they have a diameter of about 100 micro meters. So, measuring the electrical impedance across sports 1 and 2 results in 400 mega ohms and we assume that the fluid field inside this channel 1, 2 is really responsible for providing the resistance and also that resistance is homogenous.

So, therefore, if the medium is not altered there is almost always uniform resistance per unit length depending on if the channels are continuously filed. We assume there in micro flow domains still continue mechanic holds and there is almost always continuity of flow continuity. And, so therefore, in this case we make a presumption that resistance per unit length is constant.

So, the potentials that we apply for driving the flow and we have to apply perpendicular potentials perpendicular to the cross sections area the micro channels containing this fluids. So, yet ports 1, 2, 3, 4 are respectively 1000 volts 1000 volts 1500 volts and 0 volts. So, essentially you are not applying any potential at port 4 it is 0 volts you apply 1000, 1000 volts on 1 and 2 and you applying a 1500 volts in port 3. And then, you want to figure out, what is the pumping rate, what is the flow rate of such a channel architecture.

Some constants in parameters which are given regarding the surface since it is glass in contact with the aqueous based solvent zeta potential is assumed to be about minus 100 milli volts and you have to determine the direction in the flow rate if you assume that there is electro-kinetic field going on in the longest channel. And some other parameters are that the viscosity of this equals medium is about point 001 kg per meter second and the relative directly constant is about 50 we assume that the directly constant for vacuum is about 8.85, 10 to the power minus 14 farad per centimeter.

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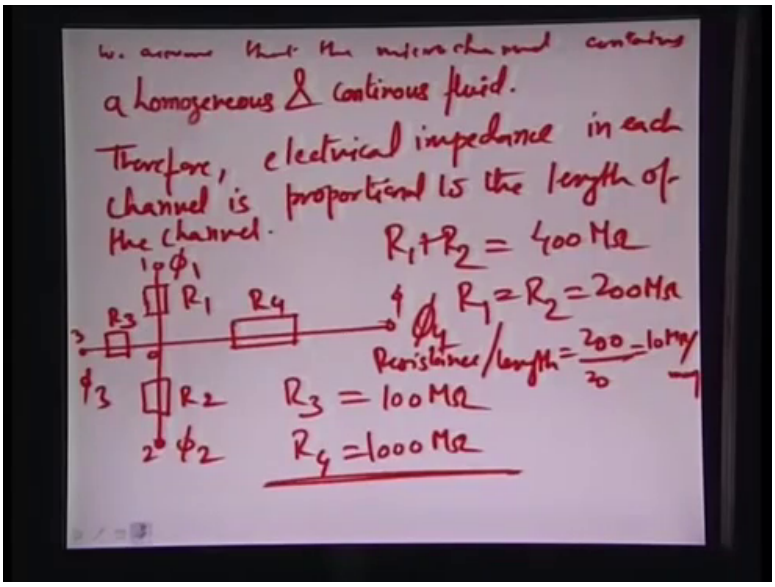

So, let us design this micro pump and the outset we assume that the micro channel system contains a continuous and homogenous fluid. So, we assume that the micro channel contains

a homogenous and continuous fluid. So, therefore, in the electrical impedance in each channel is proportional to the length, so it is proportional to the length of the channel. So, let us now, draw this network again here and we assume resistances R1 R2 R3 and R4 is an equivalent to show the resistance of the total channel we also assume this potentials $\varnothing_1, \varnothing_2, \varnothing_3, \varnothing_4$, which a value have been defined in the question, so will try to find out R1 R2 and R3 and R4.

So, as we know from the question $R1+R2$ there is a cumulative resistance across a port 1 and 2 is about 400 mega ohms. So, this is given we also know that the lengths between 1 0 and 2 and 0, so this is port 1 this is port 2 this is port 3 and this is port 4. So, the lengths the channel lengths between 1 0 and 2 0 are same equal to about 20 millimeter each. So, therefore, if you assume fixed resistance per it length really R1 becomes equal to R2 equals 200 mega ohms and the resistance per unit length in that case becomes 200 per 200 mega ohm per millimeter.

So, it is around 10 mega ohms per millimeter R3 and R4 in this case can automatically be calculated accordingly. So, the length of R3 is about 10 millimeters, which means resistance about 100 mega ohms and length of R4 is about 100 millimeters, which means the resistance about 1000 mega ohms. So, essentially R4 been in the longest channel also has the highest resistance.

So, also in done we need to somehow solve this problem using some circuit theory approaches. So, one approach that would use here, because it is considering flow of current across network of a channels are network of resistances. So, the electric aquarium electrical equivalent can easily found out by the Kirchhoff law.

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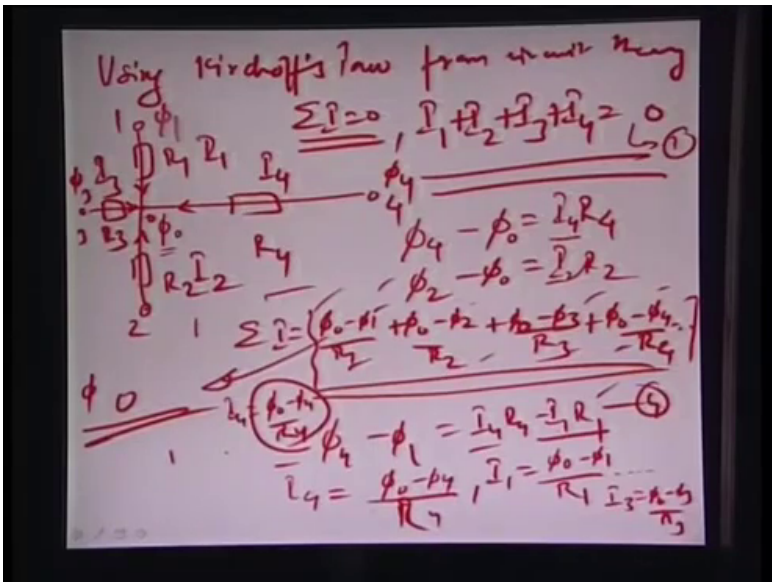

$$\sum I = 0$$

$$I1 + I2 + I3 + I4 = 0$$

$$\varnothing 4 - \varnothing 0 = I4\,R4$$

$$\varnothing 2 - \varnothing 0 = I2\,R2$$

$$\sum I = 0 = \left\{ \frac{\varnothing 0 - \varnothing 1}{R1} + \frac{\varnothing 0 - \varnothing 2}{R2} + \frac{\varnothing 0 - \varnothing 3}{R3} + \frac{\varnothing 0 - \varnothing 4}{R4} \right\}$$

$$\varnothing 4 - \varnothing 1 = I4\,R4 - I1\,R1$$

$$I1 = \frac{\varnothing 0 - \varnothing 4}{R4}$$

So, we use Kirchhoff law from circuit theory here and what this also saves as that favor to assume that there was several currents here I1 to I4, let us draw this network again for convenience. So, we have a 1 2 3 4 and resistances R1 R2 R3 R4 and also potentials $\varnothing_1, \varnothing_2, \varnothing_3, \varnothing_4$. So, if you assume that all these ohms corresponds to a current value of I1 I2 I3 and I4 notational and we also assume that all these currents are converging to this nodal point O.

Then, essentially all these currents would converge out to be 0 it is a that is what the Kirchhoff law is right sigma i at a node is 0 and this based also on the principle of conservation of energy, because we assume that an circuit any junction are any point does not introduced current by itself, where will we get the energy form. So, therefore, any current,

which is converging to an nodal diverging out of a node in all the converging to a node from all the directions is essentially the summation of that essentially 0 as know energies generated.

So, the influence in a node is exactly equal to the out flow of the current there is nothing, which is contain or nothing, which is generated at this particular node of an interest. So, therefore, let us call this equation 1 or we also try to figure out what the difference is in potential would be, so if you look at let say just the arm 4 to 2 and 4 to 1, So $\varnothing 4 - \varnothing 0$ at this particular node here. So, we can also write this as $\varnothing 4 - \varnothing 0$ is essentially the drop in potential or assuming I4 passes across the resistance R4 it is essentially I4 R4.

Similarly, $\varnothing 2 - \varnothing 0$ in the potential across these two points here 2 and 0 is also equal to I2 R2 and therefore, $\varnothing 4 - \varnothing 2$ is nothing but, $I4\,R4 - I2R2$ or we also assume in identical manner $\varnothing 4 - \varnothing 3$ and $\varnothing 4 - \varnothing 1$ to be I4 R4 minus I3 R3 and I4 R4 minus I1 R1, let us call these equations 2 3 and 4 respectively. Now, you have to play a little bit trick here, because we need to somehow solve these equation and try to figure out the way, so that we can get a relationship between essentially all the you can all the resistance in all the potentials.

So, here if we multiply equation 2 by let say R2 R3 and equation 3 by R1 R3 equation 4 by R1 R2 and some all these things up, let see what the final form of the equation would we look like. So, we have this multiplied by R2 R3 this multiplied by R1 R3 this multiplied by R1 R3 this multiplied by R1 R2 we just trying to solve, because essentially, then we will have this I4 term here coming out. And also we have this I1 plus I2 plus I3 term coming out of the resistance you know domains, so this you can blanket these I will just show in the next tap.

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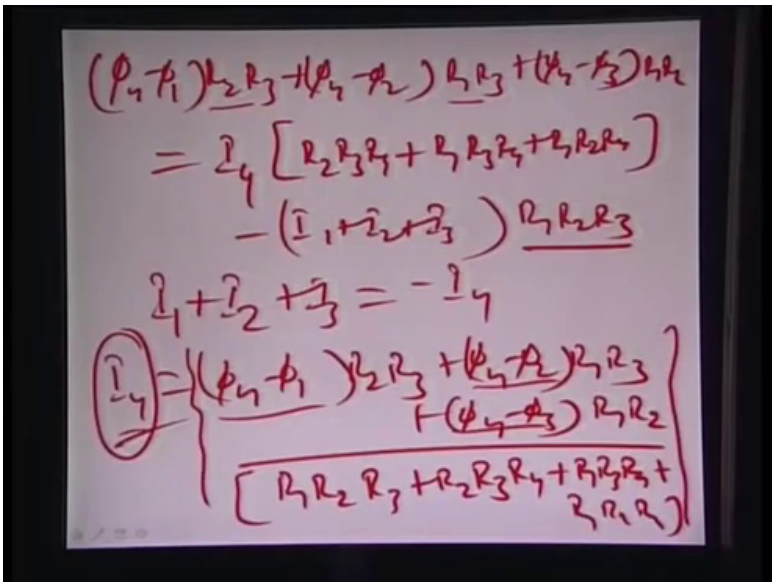

So, essentially let us multiplied and add, so we have $(\varnothing 4-\varnothing 1)R2R3+(\varnothing 4-\varnothing 2)R1R3+(\varnothing 4-\varnothing 3)R1R2=I4(R2R3R4+R1R3R4+R1R2R4)-(I1+I2+$. So, essentially we multiplied intentionally this 2 3 and 4 equations by in a manner, so that this R1 R2 R3 can be like a common coefficient for all the different current value in the second term of this equation with the minus or negative coefficient.

So the idea is the we can easily solve this particular equation by assuming that from the first equation we have a summation of $I1+I2+I3=-I4$. So, you can easily take out

$$I4=\left\{\frac{(\varnothing 4-\varnothing 1)R2R3+(\varnothing 4-\varnothing 2)R1R3+(\varnothing 4-\varnothing 3)R1R2}{R2R3R4+R1R3R4+R1R2R4+R1R2R3}\right\} .$$

So, essentially you have made this equations independent of the current, which we do not know the I1, I2, I3 and I4 values you just made presumptions or we do know, what these different potentials are we also know what this resistances are and the whole idea is to make this equation independent of the i's. So, there we can find out from the other terms, which we know already what would be the values of the different types.

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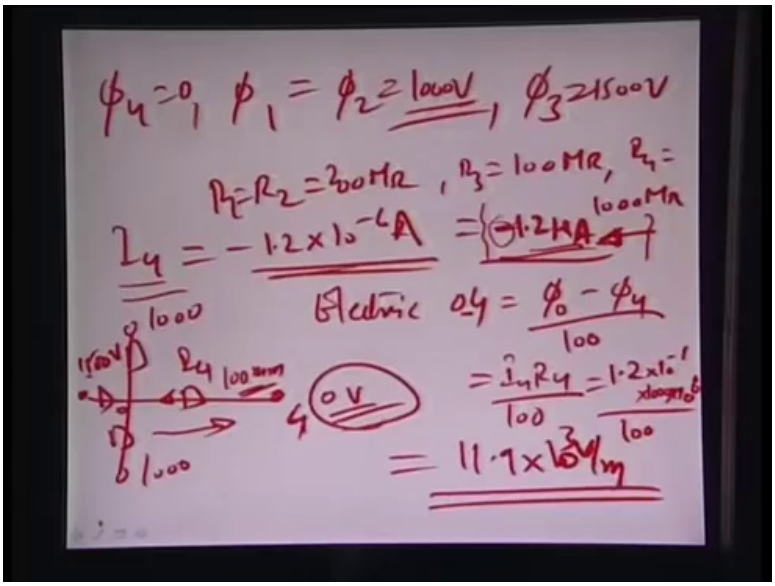

So, in this particular case if you apply $\varnothing 4$ equals 0 $\varnothing 1$ is equal to $\varnothing 2$ is 1000 volts and these are all mention in the problem statement $\varnothing 3$ is about 1500 VOLTS and you have R1 equals R2 is about 200 mega ohms R3 about 100 mega ohms R4 is about 1000 mega ohms and I4 value comes out to be equal to $1.2 * 10^{-6}$ or case of minus 1.2 micro ohm. I would just argue to look towards the dimensions or the magnitude of the current really.

So, we are really talking about very small amount of current and minus 1.2 micro ohms that is one aspect that in electro-kinetic flows over the very large amount of voltage of the order of 1000 of volts to across the capillary you really get a very small current in the terms of minus 1.2 micro ohms, the term minus here also suggest that a intent direction of I4 is really the opposite, then what it was assumed. So, if you assumed that this network of flows at the currents all converging into the node I4 was assume to be from 4 to O.

Essentially, it is in the other direction, which make sense because you have plot a 0 volt potential here and you can assume that all the other potentials 1000 of volts and both are here in 1500 volts here would be essentially putting or pushing all the fluid towards the junction 4. And, so the flow of fluid also determines or defines that the direction of the current as the current is essentially a flow fines in the channel or therefore, the minus sign indicates the current is flowing outward in an outwardly manner towards the reserve wire 4 from the junction O; that is what one issue about this electro-kinetic circuit is.

Another issue is a we also need to determine, what is the electric field in the longest channel, if you may recall the longest channel also is the one from O and 4 it is about 100 millimeters

in length. So, the electric field between O and 4 is also the voltage between O 4, which is $\frac{\varnothing 0 - \varnothing 4}{100}$ and give me a minute here we can calculate the $\varnothing 0$ value easily or $\varnothing 0 - \varnothing 4$ value easily as I4 R4 it is a drop in potential. So, $\frac{\varnothing 0 - \varnothing 4}{100} = \frac{I4R4}{100} = \frac{1.2 * 10^{-6} * 1000 * 10^{6}}{100} = 11.9 * 10^{3} V/m$. So, there is an intense amount of field, which is needed for current, which is about 1.2 micro amperes. Let us calculate the velocity of flow in the particular micro channel based on all these assumptions and so the first thing that I would like to see here is to determine, what is the mobility of the ions per unit electric field.

So, if you remember the equation that we derived on electro-osmotic flow and the mobility is also the velocity of the ion in a unity electric field new metric electric field.

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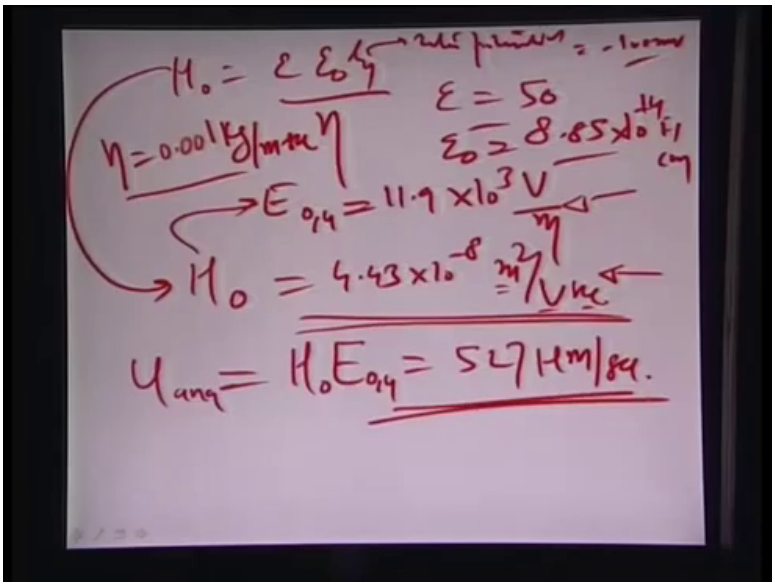

So, here the mobility can also be defined as $\mu_0 = \frac{\varepsilon \varepsilon_0}{\eta}$, epsilon 0 zeta by eta zeta is given the zeta potential of the surface as about minus ε =50 and -100 milli volts respectively. So, zeta is minus 100 milli volts and the directly constant epsilon has been given as 50 there are vacuum the permittivity of the vacuum has been given as $\varepsilon_0 = 8.85 * 10^{-14}$ farad per centimeter and we already know from our previous experience with the electric filed in the ohm length 4 that in the electric field $E_{0,4} = 11.9 * 10^{3}$ volts per meter.

We assume the viscosity here as has been given here in this question of equals to be 0.001 kg

per meter second. The mobility with all these values comes out to be equal to about 4.4, 10 power minus 8 meter square by volts per second be careful about the units here again and again, because all these units are differently classified this is farad per centimeter this is again kg per meter second this again volt per meter. And, so essentially we have to convert wherever you feel the appropriate this is milli volts.

So, in order to get meter square by volt second you have to make some convergence and the mobility or this particular flow process comes out to be $H_0 = 4.43 * 10^{-8}$. So, multiply that with the electric field here to calculate the flow velocity, so the flow velocity of the an alight here is essentially $u_{avg} = H_0 * E_{0,4} = 527\ \mu m/sec$. So, very interesting because this is only have a half millimeter per second.

So, if you apply such a high potential about 1000 volts 1500 volts of the order of the 1000 of volts of potential you are getting a current, which is almost in the range of micro ohms, which again causes the flow, which is essentially only half in the millimeter per second. So, therefore, this really is not a very high healed process in terms of applied energy and the output it may not be very highly efficiently process; however, that advantage the electro-kinetic flow has to offer is in many situations we do need flowing mechanism without any mechanically active components in the device.

There are several micro component models and we will doing covering some of them in the later half this course, where we can use mechanical motion to generate flows like this with the micro scale architecture. In some other instances we probably do away with the mechanical motion, because of the softness of the material that we are dealing specially if you are talking about the logical entities like cells proteins are molecules would be a rapid confirmation change particularly in proteins as we flow them into micro channels to do some diagnostics do some something important and useful.

There what would be important is to carry the molecule of the entity using alternate mechanism without using non mechanical method there is no active components in the circuit. So, electric-kinetic flow definitely is one simple mechanism and all though the process may be not a very high throughput high in to one preferable, because it is probably one of the more available where you can transport fluids by just rapidly applying an electric field.

And also it is more integrable to micro electronics, because you can apply these high voltages through screen printed electrodes across both ends of the channel very easily. So, even though

on the velocity only half a millimeter per second it sometimes works out to be a very process comparison to the other conventional country parts, which are available. We have another simpler method of a solving this whole problem and this again is based on the Kirchhoff's law here.

So, let me just is go ahead on, so you quickly what we can do. So, essentially as we know here and the $I4=\frac{\phi 0-\phi 4}{R4}$. And similarly the $I1=\frac{\phi 0-\phi 1}{R1}$, so and, so forth and $I3=\frac{\phi 0-\phi 3}{R3}$.

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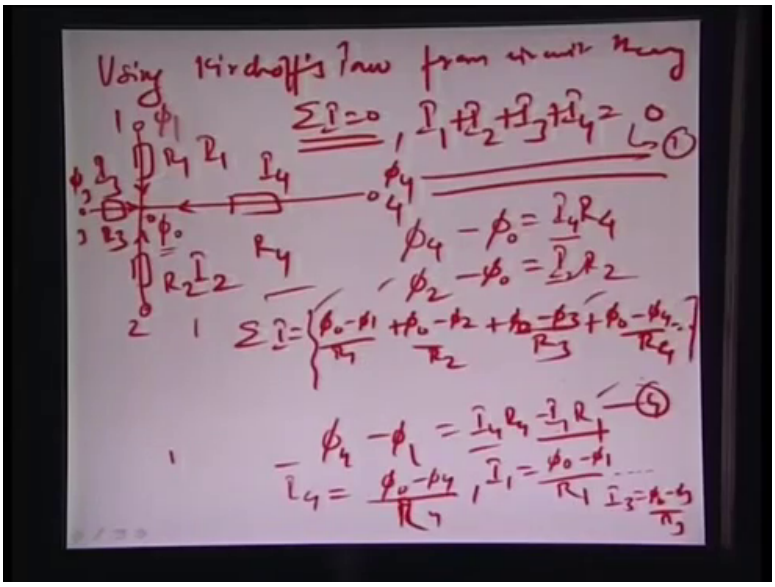

So, whatever we have done in this can be more simplified by just a putting this various I values in the first equation of the Kirchhoff's law and we able to tell what or how it will behave.

$$\sum I=0, I1+I2+I3+I4=0$$

$$\sum I=\frac{\phi 0-\phi 1}{R1}+\frac{\phi 0-\phi 2}{R2}+\frac{\phi 0-\phi 3}{R3}+\frac{\phi 0-\phi 4}{R4}=0$$

So, this actually brings as to the same equation as we have talked about here, where we were trying to calculated I4 is.

So, this another very simpler method of a finding out what the, so for here you can find out the $\phi 0$, which is a known actually, because we have only one variable and one equation and other parameters $\phi 1$ to 4 and R1 to 4 are all known other from $\phi 0$ we could

easily find out I 4 is just by calculating phi 0 minus phi 4 by R 4. So, it is what simple method of mathematical estimation in comparison to the other method ((Refer Time: 27:44)).

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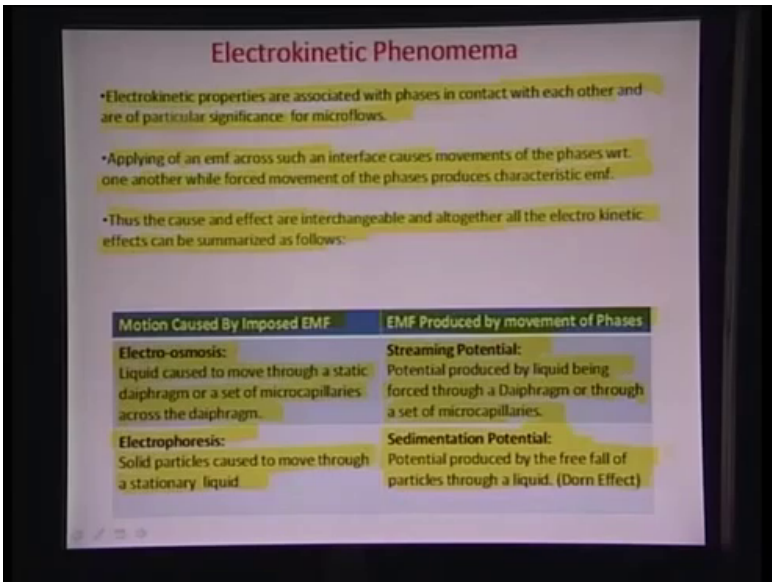

So, that inertial how you can design electro-kinetic bobbin mechanisms and what have would be interest with next with you are essentially finding out the flow rates in terms of value in the charge.

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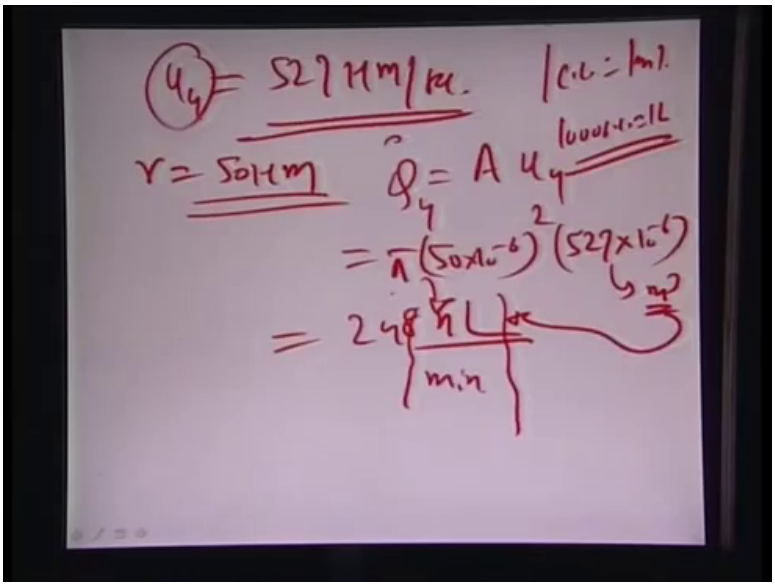

So, we also know that we have already obtained a flow rate in the fourth arm $U4$ as 527 micrometers per second we have been given that there radius of this particular channel in question is about 50 micrometers. So, the radius is about 50 microns and calculating flow rate

here is really not a problem essentially the area across section times of u4 and

$Q4 = u4 * A = \pi * 50 * 10^{-6} * 527 * 10^{-6} = 248 \frac{nL}{min}$. this is of course, meter cube.

So, you have to do this conversion meter cube to nanometer 1 centimeter Q is essentially 1 m l. So, about 1000 c c is make a about 1 L, when you are talking about 10 to the power of minus 9 L. So, it is about 10 to the power of minus 6 times of meter cube, so that is in actual, what the volume florid would be. So, you again find out that this volume florid of a couple of nanometers per minute is relatively a very small quantity as is characteristic of this an alternate mechanisms of a micro channel flows.

So, in and actual electrochemical electro-kinetic property is an associate with the phases and contact for each other and of particular significance for micro flows applying and EMF of across such an interface causes movement of phases with respect to one other by close movement of physics can insist of EMF. So, the cause and effective, where really interchangeable and all together all the electric-kinetic effects can be summaries thousand motion caused by impose EMF or EMF produce by the movement of phases.

First category as we know already phenomena like electro osmosis electrophoresis, where motion is cost by applied EMF electro osmosis, where liquid is caused moves to a static diaphragm containing set of micro capillaries are in any case though a micro capillary in general the by applying and we used EMF electrophoresis in the other hand is very solid particles cost in move through a stationary liquid by applying and extend electric field.

So, by for the other mechanism, where EMF is really produce by the movement of a phases the first property is a streaming potential, which is also the potential produce by the liquid, which is being first through a diaphragm also a set of micro capillaries. So, and also sedimentation potential the potential produce by the free fall of particles specially when they are suspended in a medium liquid medium is also known as the down effect. This is also mechanism and chemical industries to find out a lot of information about the quality of you know the collide, which is present which is under investigation.

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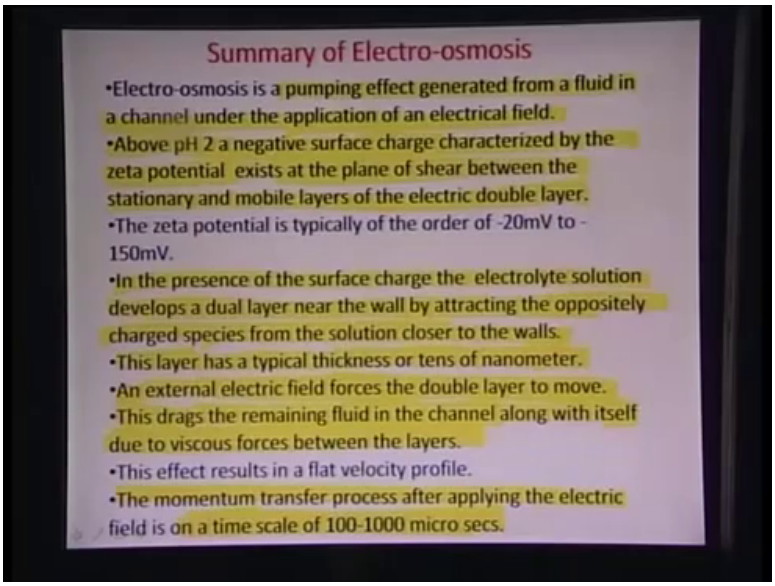

So, for electro-osmosis summarily we can say that is a pumping effect, which is generated from a fluid in a channel under the application of them external electric field. So, as you take the pH of the contacting phase, liquid phase surface to about two the surface immediately develops in negative charge characterized by the zeta potential and this exist at the plan of shear between this stationary and the mobile layers of the electric double a that is formulated.

So, there is a layer of diffused charges through the medium starting from the double layer all the way activate a charge density falls to almost 0 the zeta potential typically is a order of a few times of mini volts to hundreds. So, typically about minus 20 milli volts, so all the way to about 150 milli volts also. So, in the presence of a surface charge the electrolyte solution develops in dual layer near the wall by attracting the oppositely charged species from the solution closer to the walls and this layer typically has a thickness or tens of nanometers very small layer very closed to surface.

In this situation if a plan external electric field forces that double layer to start moving. So, there are this instance where the ionic forces generated by the external field kind of a does away with the holding force for the discuss forces in between the layer and it causes the shear of this fluid along with the double layer. So, there is a static fluid facing the wall of the capillary and there is a shearing across this double layer and a following this the that the particle liquid which is between the two double layers are between the whole this double layer talks to move with a uniform velocity towards one of the electrodes depending on what the potential the zeta potential of the surface would be as a plug like flow.

So, they have a uniform velocity while flows and this drags the remaining fluid in a channel, because a shear motion and a very small channel would essentially mean a lot of that forces generated and across the ions and these are. So, due to the discuss forces which exist between the charge particle and the fluid. And therefore, at the due to this discuss forces and the layer start moving the whole liquid, which it is invested are suspended in.

So, this effects result in a flat velocity profile as we have a seen earlier and the momentum transfer process after applying the electric field is approximately on a time scale of about hundred to thousand microseconds. So, you have a just a about wait for about close to one millisecond to be able to get in existential move into effects see now, we just within the channel.

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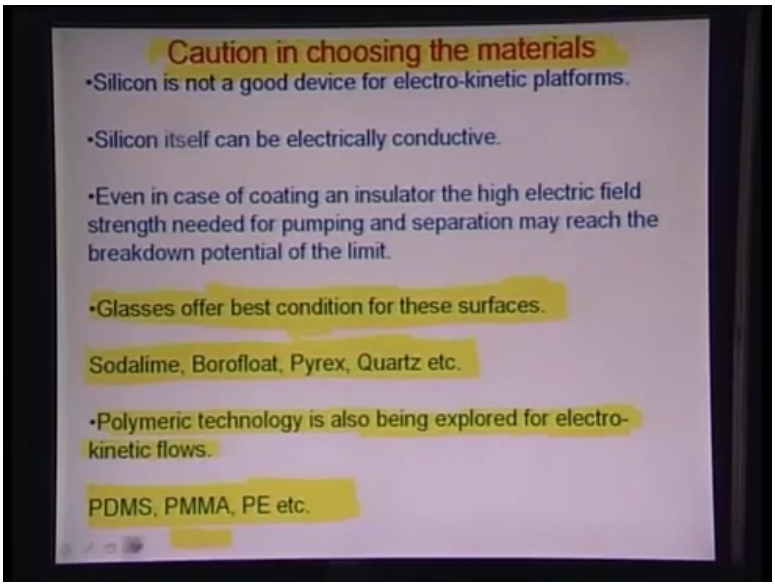

So, there has to be a certain cause and choosing materials especially for the electro-kinetic applications silicon particularly is not really a good device for electro-kinetic platforms as a, because silicon itself can be electrically conductive depending on whether it has opened material. So, silicon typically changes behavior from being insulating to be conducting, because that is how the semi conduct is behave the bank of that they have is essentially a function of temperature.

It all depends on if there are few electrons, which are the balance band get thermally exited to the conduction band or not and certain temperature. So, it is really not a very good device for an electro-kinetic platforms and you know what will happen by the by if the platform is electrically conducting the current will rather flow through the silicon there none be any

register and movement, because of this. So, it the flow through the silicon in general silicon would be a short circuit in that application.

On the other hand, classer do offer pretty good surface for a investigating exploring such kind of flows you know different type of classes Sodaline, Borofloat, Pyrex quartz etcetera. So, glasses to offer a better condition in comparison to silicon and one of the reasons is that glass is a better insulated, then silicon is silicon essentially is a silicon method is it has a very different band gap in a structure, then what insulated do have to offer.

And solve the glasses, which have commonly use Sodaline, Borofloat, Pyrex quartz is a very clean form of a glass interior essentially it has a very clean soft and spectrum one of the pears forms a classes it is available as very good for optical detection as well. So, in electric-kinetic applications there are lot of a research initially, which have been taken in the area of a protein and movement the florescence read outs is one of the ways of detecting how these molecules translate cross a this particular chips.

And, so therefore, glass also provide additional advantage that can have a good transaction mechanism, optical mechanism can easily executed are executed in the optical transparency of a the glassy material. Of course, a if you consider propagation protocols silicon has a very well define protocol of etching wet or dry depending on whether the ((Refer Time: 37:24)) is a gas phase on liquid.

Glass of course, can etched using a mostly what in techniques and depending you know it has to the process essentially has to be done the clean area and this has to also be disturbed, where very small thing an architectures we in the micro after developed filled if you recall the example that we showed in the last few slides of designing an electro-kinetic proper network, the diameter of the capillary in question 100 microns.

So, you cannot etch 100 micron feature without doing for the lithography step preceding in the step. So, whether it silicon of glass this techniques are very useful only, because of the fact that this micro systems technology fabrication technology area has been very well developed. Polymers as we know has also substantial amount of a advantage being bio friendly and also flexible to amenable an fabrication techniques in polymer technologies also being explored for electro-kinetic flows specially materials, which can change of get oxidize on expose it to gas plus mass like PDMS, PMMA polyethylene are these are some materials, which can from this shall in all kind of bonds SiOH bonds on their surface and exposure to some gas plasma systems.

Such surface modification is being explored and exploited for a motion of charge molecules using this concept of an electro-kinetic force. So, there has to be definitely some out of cause of in choosing the materials for designing the electro-kinetic flowing systems.

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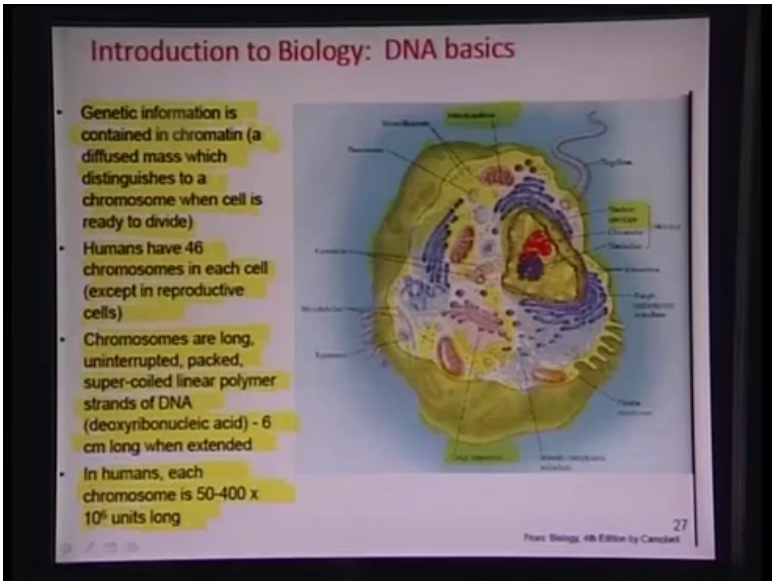

So, let us actually now delve in to a little bit of a y z really that we need this all different techniques of sensing or transport to do analysis or r to be diagnostic. So, I would like to just explore some places preliminary level topics in biology is a part of this course because this would be important for understanding and the utility of these areas well. So, let us look at one of the most fundamental you know building blocks of our own systems our own human body the cell.

So, the cell as know is the smallest unit the repetition of which can make tissue the body is comprised of a millions of this tissues and there is an engineering aspect associated with the way in the cell behaves. And it is wonderful to assume that all over body functionalists or in a level of equilibrium the and any deviation from this a normality it is like an equilibrium reaction it automatically cause and effect and their efforts can lead or essentially would lead to taking the equilibrium back to the two charge in a position.

So, let us see what all constitutional there in cell to begin with, so cell essentially has membrane this here if you see here in this area is the cell membrane it is a made up of a liquid by-layer and there are molecules, which are floating in this liquid by layer molecules like proteins as if they were moving through a jelly. So, essentially this layer here is more like a cutaneous membrane, which holds together what is there on the inside of this cell.

So, in the inside we have thick liquid also known as cytoplasm you can see this here essentially is the liquid, which is all sparse around and this is not all to get because there are certain a small organelle, which float around in this liquid in each of the organelles has a different purpose and a goal like. For example, we have this mitochondria we have endoplasmic reticulum which is also the protein warehouse of the cell we have bodies and then we have something which is nerve center of many cell the nucleus.

So, essentially we would be more concerned with happens in the in the nucleus and how the nucleus essentially a programming computed for which defines what the cell has to do or it is next step in the life cycle and a therefore, it is very, very interesting for an engineer to be able to delving into this and learn some lessons from what mother nature has to offer one of the finite prices of one of engineering and then it has ever created. So, in the nucleus most of the genetic information is contain with the area called chromatin.

So, diffuse mass which distinguishes to a chromosomes when a cell is ready to almost divide by, so essentially the genetic information is somewhere in this particular region here this is all present as chromosomes and chromosomes are this double Y shape structures something like this. So, two Y's coming out that both n and what the chromosomes has as an essentially a set of a highly compressed super coiled DNA.

So, if you look into the human system we normally all size in the human system have about forty six chromosomes in each of the cells except the reproductive cells where there are 23 and essentially the idea is that the two reproductive cells from either success come together to produce in the 46. So, the chromosomes essentially is also responsible for replicating cell into another cell or creating what you call life. So, it is a kind of program on a code, which has been given by mother nature for the cell to be identically able to duplicated itself into two or more forms from it is own form.

So, the sense in the human system has about all cells as a about a 46 chromosomes and all except the reproductive cells in the human body share this number and as we indicated before chromosomes are long and interacted pact super coiled linear polymer extends of DNA molecule and just to add the few surprises for you the super coiled form of DNA in a chromosomes if we just open up and spread around it can be as long as about 6 centimeters. So, starting from a small molecule a bunch of different molecule this molecule can extend all the way to about 6 centimeters.

So, can you imagine the kind of compressing density that it has the nucleus could be about

close to micron size. So, you can think about that how much amount of comparison is needed for compressing something, which is about 6 centimeters of length into almost about a micron cube size volume. So, it is a really, really high pack structure, which is available in form of a chromosomes. So, in humans each chromosome is essentially about 50 to, 400 into 10 to the power of 6 units long by unit I base pair.

So, this about how much you will have in one chromosome in terms of the different base pairs in DNA. So, about 400, 10 to the power of 6 units or base pairs on 1 chromosome if you consider the whole DNA spread it out and see how many base pairs are there it is as high as 400, 10 to the power 6. So, this is the kind of number of molecules, which you are also essentially packing into this small and area.

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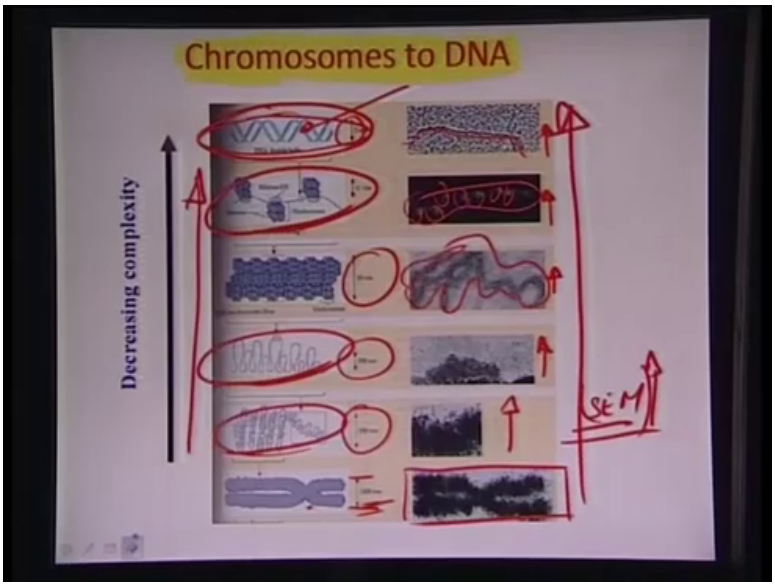

So, this is a very good illustration here if you look at a you know what modern science in physics has to often in terms of imaging modalities. So, in the left here is essentially an animated sequence of how you can go from a chromosome, which is a double y shape structure all the way to single molecule of the deoxyribonucleic acid. So, here it is a super coil super compressed structure in form of a double line and here if you just keep on opening this in the various steps you seeing here it just about beginning to open this super coil structure step by step.

Then, you combining to a form here which is the DNA molecule this is essentially what really happens there use in scanning electron for graphs seem to decide for what is going on here. So, you have case 1 here which is a really what the chromosome looks like it is this

double y shade up structure you blue it up a by increasing the of the magnification and find out there it slowly goes all the way up to the level of a single DNA which is pretty much like this.

So, these are the individual base pair is here if you see and this is how DNA would look like and this is the back born of the DNA this is a called and coiled DNA a is going to somehow look like. So, this is a real scale that what happens if you look at a chromosome by increase magnification it is kind of analogs to this much here, which is a more and animated in which. So, here the scale is about 100 nanometers this size is arrow is about 100 nanometers I am 1000 nanometers this arrow here is about 100 and 1400 nanometers this arrow on the top here is about 200 nanometers 300, then you have about a the third in meters 11 and 2 nanometers find.

So, this is essentially the highest magnification you resolving a length, which is already in 2 nanometers represented by this arrow here. So, it is decreasing complexity are increasing magnification that you are looking at this gives a sequence of, what DNA would be from extracted from a chromosome.

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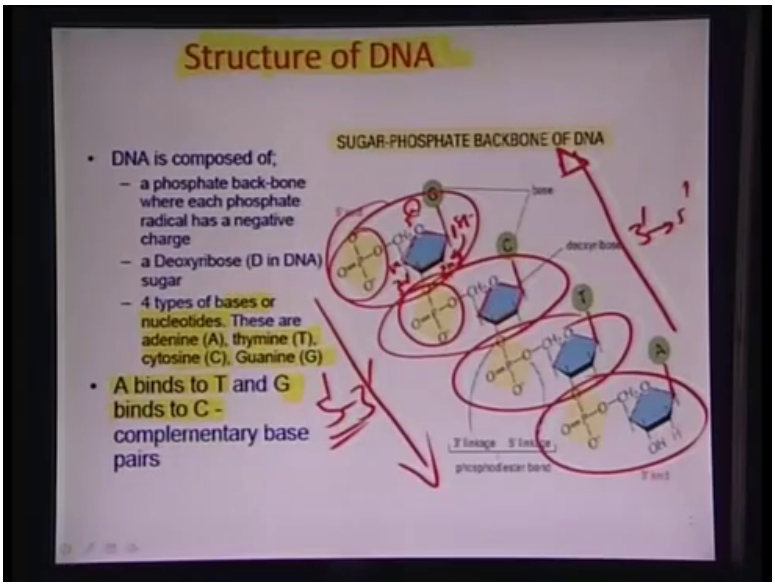

Let us look a little more include what a DNA molecule really I would look like a behave. So, DNA a essentially is like a twist that ladder it is you take a loader you know what a ladder is right and. So, in a ladder you have several of this connecting peaces in between two sides 2 2 to plans and this connecting pieces are essentially the steps for a ladder right. So, if you take a ladder and twister and give small rotations and try to twisted there is how the DNA molecule

essentially is made up of.

So, the flanks of the ladder the analogous part in the DNA is essentially this sugar phosphate backbone. So, you have a first carbon ring here as you see and you also have a phosphate linkage between two such 5 carbon rings. So, this is a one ring this is the second ring that is a phosphate linkage between both the rings that is also kind of a rotational presentation that this all molecules possesses. In fact, biochemistry has been very organize approach of how to grade and number the different positions in a certain molecule of the different atoms.

So, here we start with this particular carbon atom and call it the first carbon and we move in a clock wise manner. So, this is the second carbon this is the third carbon this is fourth carbon and this is essentially the fifth carbon. So, when we are going from let say bottom to top here essentially going from the three prime to 5 prime side and I going from and the other direction we have coming back from the 5 point into the three point. So, also at the first carbon we have a several this base pair groups, which are essentially covalently bond it to the first carbon of the sugar molecule and therefore, such a groups in DNA are adenine, thymine, cytosine, guanine.

So, typically four types of bases are nucleotides and also very interesting factor or a very fantastic mechanism of this arrangement of molecules is that this base pairs adenine, thymine, cytosine, guanine only bond to its counterpart; that means, adenine binds to only thymine, guanine only binds to thymine just see a little bit why this happen. But, then the idea is the adenine cannot bind to cytosine, or guanine cannot thymine vice versa and this is a very fascinating you know event, because essentially there is some kind of a ordering as that mother nature has a dramatically provided by ensuring that all is specific bondage between two molecules out of all the 4 is allowed.

So, if you have sequence of base pairs on one side you only have a complimentary sequence of this base pairs other side, which is corresponding to the molecule of interesting it is given you certain can be selection probability are it is maybe probability of selection of a certain sequence higher over the other sequences this is a fascinating approach of thing that a mother nature has to offer this is one of the principles of the diagnostics also that if I have some we able to find out what is there on one flank I should be able to product what is there in the flank of the molecule in terms of the bases. So, let us look into a little more detail is of a in this structure of how this bases are realized.

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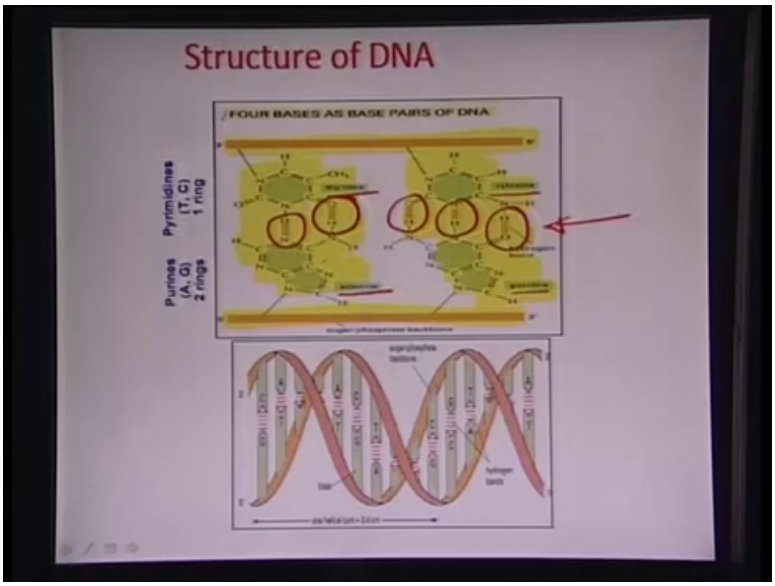

So, if you look at this particular figure here you have the backbone the sugar phosphate backbone represented as that is orange thick lines and both sides on the base pairs here are essentially connections between these two orange lines and you have thymine inside and guanine inside. So, the fascinating fact about this is that if you look at really the thymine and the adenine bond. So, we are looking at the thymine and the adenine bond here. So, we find out that there are only the two hydrogen bonds between the two moieties.

So, there only two work centers two bonding centers between the two moieties, where if you look at the cytosine, thymine coupling appearing you have the three hydrogen bonds between these two moieties. So, know the reasons why make for offer this selectively this unit selectivity of complimentary pairing if you have three hydrogen cytosine bonding to let say two active side adenine vice versa that is going to be a thermodynamic problem it is going to be non stable structure in the bonds or not completely fill. And, so therefore, a greater probability would be that the molecules, which two hydrogen bonds would the bond to the molecules only with two active sides and the similarly the molecules with three hydrogen bonds would alternately bond to molecules with three actives cell.