Microscale Transport Processes

Prof. S. Ganguly
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Module No. # 01
Lecture No. # 23

Dielectrophoresis

Welcome you to this lecture of Microscale Transport Process. What we have started discussing in the last class is electrophoresis. We completed our discussion on this electric double layer, and electro osmosis process and while concluding I said that, it is there is another such electro kinetic movement, electro kinetic motion, which is possible by the mechanism which is referred as electrophoresis.

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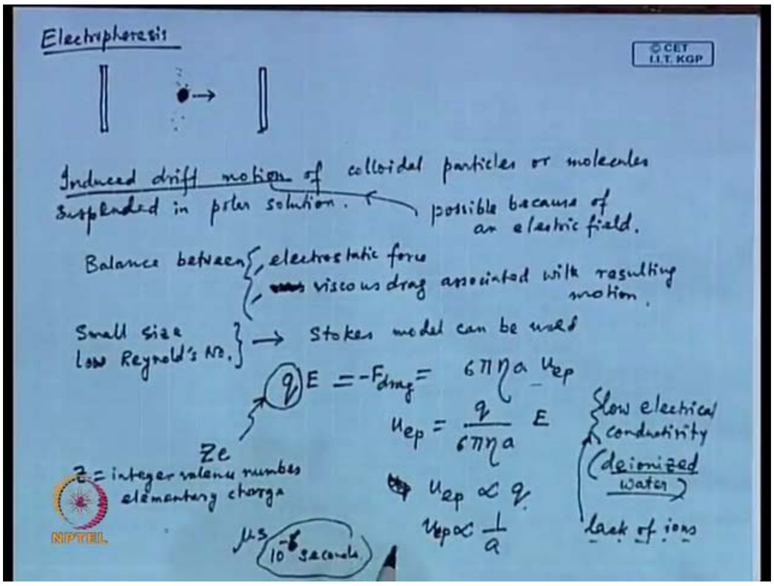

Electrophoresis

Induced drift motion of colloidal particles or molecules suspended in polar solution. ← possible because of an electric field.

Balance between { electrostatic force, viscous drag associated with resulting motion.

Small size, Low Reynold's No. } → Stokes model can be used

$\boxed{q}E = -F_{drag} = 6\pi\eta a u_{ep}$

q ← ze

z = integer valence number, elementary charge

$u_{ep} = \frac{q}{6\pi\eta a} E$

$u_{ep} \propto q$

$u_{ep} \propto \frac{1}{a}$

{ low electrical conductivity (deionized water) ← lack of ions

μs (10^{-6} seconds)

In electrophoresis what we have is, an electrode or rather two electrodes would there, and we have some charge some particle with a size and a charge, this particle is defined with the charge on it and the size of this particle. And depending on the charge and the size, these particle would be pulled towards one electrode that that is idea here.

Obviously, you can you will appreciate that, if the charge is highest and if the size is smallest, the particle will attain the highest velocity. Typically, the velocity is attained within within few micro in a in a very short time. Now, what is the, I mean, why it should not be accelerating all the way? Because, there is a balancing force, which is which we refer as drag. So, basically it would be the pull by the electrode and that would be balanced by the drag force.

So, these these two forces, they counter balance each other and when these two forces are balanced, these particle would be attaining a constant velocity. It is like, you remember that, settling will terminal velocity during settling and those kind of things, it would be I mean you you need to take this in a in a in a similar say similar context. So, so you have this particle which is moving at a velocity and at the same time it would, it is experiencing a drag and these two forces are balanced and these defines the constant velocity, the particle attains.

So, if there are several such particles of different sizes and different charges then, if you experience these these ensemble of particles this mix crowd, if you put them in between the two electrodes; then these and and if you if you expose them for certain amount of time, you will see that particles of same size or particles of same charge I mean, they they would be moving at a same velocity. So, you would be you would be classifying these particles within within these within these medium that that is that is the idea.

So, which particle reaches the other end or or you can you can have a calibration done and using that calibration, you can you can identify the particle. So, this is this is basically the method that is used in electrophoresis. So, if I if I try to (()) what these what this process is about I would like to write it as, in electrophoresis the topic is, topic for today the first is electrophoresis, before we go to the other item dielectrophoresis. Here, this in electrophoresis what we have is, induced drift motion of colloidal particles or molecules suspended in polar solutions.

Now, these induced drift motion is possible, because of an application of electric field. So, these induced drift motion these induced drift motion this is possible, because of an electric field. So, this is basically the, so this is a balance between, so this process is a balance between balance between electrostatic force and the viscous drag associated with the resulting motion. So, electrostatic force and viscous drag associated with the resulting motion. So, this is this is these are the two forces they balance each other.

Now, because of small size small size and low Reynolds number, you cannot expect that the particle would be moving like a like a ballistic ballistic item, it is it is it is like small, so it would be like low Reynolds number, small size and low Reynolds number. So, these means that, stokes model can be used. So, stokes if stokes model can be used then, these drag force can be given by the stokes model.

So, what you would be writing in that case is that, q into E, q is the charge on that particle and E is the electric field that has to be equal to F drag, that is the drag force. And this drag force is given by, 6 pi eta a u e p, u e p is electrophoretic velocity; that means, the velocity attained by the particle at steady state I mean we said that, at steady state these forces are balanced. And so, at steady state, you it reaches the steady state velocity and this is an observation that it reaches the steady state velocity very quickly. So, this is that steady state velocity u e p. So, this gives, this is the definition for drag (Refer Slide Time: 07:13).

And as a matter of fact, I think it should be then that is it is it is actually this is, this should be equal to minus F drag, these two forces are the sum of these two forces equal to 0. So, q E is equal to minus F drag, which is equal to this quantity. So, and this q the charge this is basically I mean you can you can write this as, z into e. What is z is the integer valence number, z is equal to integer valence number and e is equal to elementary charge.

The value of e, I have already indicated in my previous classes previous lectures. So, you need to go back to the notes, e is the elementary charge and z is equal to integer valence number; that means, if you are talking about some some ionic dissociation, then it is whether it is plus 2 or minus 2 it for example, (( )) it would be plus, the valence number would be 2 in that case, so its its like that, NaCL it is the valence number is 1, so this z signifies that.

So, this q is equal to z e and you would be writing it as, q into E is equal to this quantity. So, in that case you can write u e p, that electrophoretic velocity that is equal to, you can write this as q divided by 6 pi eta a into E. By the way, you would you you understand this the other components of the drag force I mean I am sure, this comes from stokes law it is it is a in fact, if time permits we can we can discuss this, how how we have gotten because, this is these are very general treatment I mean, it is not specific to a microscale process. So, I am not I mean, I am not talking about it.

Here, is this is this is a very basic definition of drag force using stokes model, eta is the viscosity within which the in fact, we have discussed this stokes model while defining diffusivity I remember, right; when when we defined diffusivity at the very beginning of this course Stokes-Einstein formula, there we talked about this formula. So, we we have discussed this before, eta is the viscosity of the medium, and a is the radius of the particle radius of the particle.

So, 6 pi eta a and u e p is that terminal the velocity, that steady state velocity this particle is reached. So, this is then u e p, this is the formula. So, what does this u e p means? u e p in that case, u e p is proportional to q and u e p is inversely proportional to a; So that means, this velocity depends directly on the charge, if there is more charge on the particle, then the particle would be attaining higher velocity; and if it is there is less charge on the particle, it would be moving slowly. On the other hand, if the diameter of the particle is if the diameter of the particle is small, then it will have a higher velocity.

So, if these there exists some mixture of particle, one some are big, some are small, some are having higher charge, some one having lower charge. So, they will attain different u e p depending on their size and charge right. So, if you expose them for some time within this system, you will see that particles of certain size and charge, they will be moving faster than others, so they will classify themselves. So, that that is exactly what we are looking at.

Now, this liquid should be of low electrical conductivity that is one criteria we have here, a liquid should be of low electrical conductivity. A good example of low electrical conductivity would be deionized water. So, if you if you have a sample, you should put it in I mean if you if you expect that sample which is containing particles of different sizes and if you expect those particles to be attaining different velocities then, in that case you should be putting it in a medium, which is having low electrical conductivity an example would be deionized water.

And because this this low electrical the the if if you if you do not have low conductivity of the liquid, low electrical conductivity of the liquid means basically these implies, there is lack of ions, lack of ions and these ions, if if if there is more such ions available from the medium itself then, these ions would have accumulated around the charged particle and partly neutralized its charge.

So, if the if the if there are several such ions already available from the medium, so they would be they would be getting attached or they would have accumulated around the charged particle and they will partly neutralize its charge. So, it will not be (( )), so you will be working with a less q in that case, so you will not be getting the level of sensitivity or the level of motion that you can expect otherwise. So, it is important that you expose it to the deionized water.

And typically, this process is within a very short time scale, very short time scale means within few microseconds, microseconds means 10 to the power minus 3 or 10 to the power minus 6 seconds 10 to the power minus 6 seconds. So, within a few within within 10 to the power minus 6 seconds, they reach steady state, this particles reach steady state, this is this is what basically what we have as electrophoresis.

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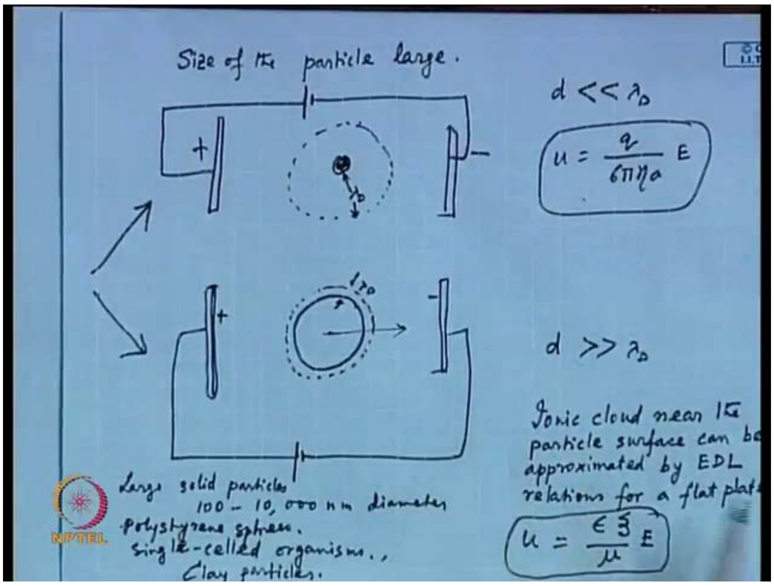

Size of the particle large.

$d << \lambda_D$

$u = \frac{q}{6\pi\eta a} E$

$d >> \lambda_D$

Ionic cloud near the particle surface can b approximated by EDL relations for a flat plat

$u = \frac{\epsilon \zeta}{\mu} E$

Large solid particles 100 - 10,000 nm diameter

Polystyrene spheres.

Single-celled organisms.,

Clay particles.

Now, there is one issue here, as the size of the particle is important here. If the size of the particle is large, if the size of the particle is large means, how large? What is what is the definition of this large, that is that is is there, that that that problem is there. So, the idea here is, you have an electrode, you had a set of electrodes, you have a particle.

Now, if this is a small particle and this has this is the Debye length in that situation, this can be one case. And other case could be, you have a set of electrodes and you have a large particle and the Debye length correspondingly is smaller. So, there are there are two such situations possible. So, here it is plus, here it is minus, so you have you have connected these and here also, you have this is plus and this is minus and you have connected this.

Now here, this charge is say plus here (Refer Slide Time: 15:27), here this charge is plus, so this would be attracted, this would be moving towards this direction. Now, this distance is I said Debye length, so that you look at the radius of the particle or diameter of the particle, and that is small compared to lambda D, the Debye length, lambda D we have already discussed in connection with electro osmosis or electric double layer right. So, this is this is that same lambda D we are talking about.

So when, so you have two situations, one is d much less than lambda D, another situation where d is much greater than lambda D. Because, this is lambda D, bottom line is basically the one, in one case the particle is small and the other case, particle is big. What is an example of a big particle? Big particle could be say for example, this particle we say is I mean we are talking about large solid particles of dimension 100 to 10,000 nanometer diameter, polystyrene polystyrene spheres, single-celled single-celled organisms, clay particles clay particles.

So here in these cases, we have said that this, d is much greater than lambda D in that case, the ionic cloud near the particle surface can be ionic cloud ionic cloud near the particle surface near the particle surface can be approximated by electric double layer relations for a flat plate for a flat plate.

And then in that case, u would be equal to epsa zeta by mu into E, do you recall this expression, we have we have used this expression we have used this expression in connection with electro-osmotic velocity, u e o. We have talked about this expression before we you remember with this we have that 1 minus that that cos hyperbolic something divided by cos hyperbolic h by 2 lambda D, so that expression was there. And we said that, for a major part of the channel, this is the velocity that is prevailing. So, this was u e o that time we referred this as u e o the electro-osmotic velocity.

So here, what they are saying is that, since this particle is large and this Debye length is small, so the ionic cloud near the particle surface can be approximated by E D L relations for a flat plate. And then the velocity, now this u e p this electrophoretic velocity for this particle is nothing but, the velocity electro-osmotic velocity of this double layer, that is what they are, that is what the argument here is.

That, this this the particle is too large, so the double layer that is formed around the particle, what would have what would be the velocity of that particle, so that that would be governed by electro-osmotic velocity; and that is that is what would be governing the motion of this particle, that is that is how that is how the treatment would be.

So and and this when this d is much less than lambda D, this is the classical case of electrophoresis we have already defined this. What was what was our formula then? u is equal to, what did we say, q divided by 6 pi eta a into E right, so this is this is this is the formula that we already found here. This is the formula that that already we have found here by using using by balancing the two forces, electrostatic force and viscous drag.

So, that this formula would be would be valid, when you have d much less than lambda D; that means, diameter of the particle is much smaller than the Debye length; whereas, when the diameter of the particle is large compared to the Debye length in that case, this ionic cloud near the particle surface can be approximated by E D L relation for a flat plate, and movement of this layer would be governing the velocity of the particle.

So, these these are these are the two equations we have now. Now, one thing you must note here is that, in this expression we do not have any diameter of the particle involved right. In this case, we do not have any dimension of the particle. So, this is, so basically what we are talking about is two regimes, this is one regime (Refer Slide Time: 21:56), and this is another regime.

In this regime, when d is much greater than lambda D, the effect of particle size is not there I mean dimension of the particle does not I mean whether it is, this big or little more little bigger, they will that will not affect the velocity of the particle. So, based on the particle size I mean suppose, you have particles of same charge, but of different sizes, but if the if you are in this size, if you are in this regime, you cannot differentiate you cannot you cannot I mean this this will not help you, that is what it says.

But anyway, we are talking we are were here we are talking about the molecules etcetera and here, we are talking about the the what we call, large solid particles, polystyrene sphere, single-celled organisms. So, these are these are different dimension all together. So, this is this is I would say, all I had as for as the electrophoresis is concerned.

So, you more or less you have you have some background in in what what we have, what we are talking I mean, what we mean by electrophoresis, and how the treatment would be, if we if somebody wants to know that, what what would be the velocity, and what would be the extent of movement of particles of certain charge and size.

Now, now on top of this I mean I do not know whether I mentioned this in the beginning in the introductory introduction lecture is that on top of this, they have they have something called gel electrophoresis, where they in the medium itself I said it, it should be deionized water right, the medium should be deionized water and within that, the particle should be moving.

Instead of deionized water, people have used hydro gel, which is a matrix gel matrix you have some idea of what hydro gel is, I mean I am sure, you have that, it is basically it it is predominantly water with some polymer and cross linker put together. So, it forms a network, it forms polymer network within which the water would remain trapped.

And now, these ions they can they they will they can move through these or or the molecules, they can move through these gel network. If you if you take a gel and if you put ink on top of gel, you will see the ink is percolating, it is it is defusing into this medium. So that means, it is it it is like it is it is acting like a porous matrix, there would be diffusivity, but that diffusivity would be scale down.

For example, if you if you are looking at say an ionic diffusivity obtain to be power minus 5 c m square per second in a in water. In water, if you look at it that diffusivity, then when it comes to hydro gel, which is predominantly water with some gel network, you would be getting diffusivity, which is an order of magnitude less. Because, there would be some amount of (( )), these molecules have to encounter while diffusing through this medium, because of this porous structure.

So, some people have there it is it is a convention in some places to use gel instead of deionized water. So, in that case, gel offers extra screening I mean particle of certain suppose, you have particles of different sizes and you want to screen. So, particles of certain sizes, gel will not allow those particles to pass by, gel gel gel offers another level of screening. One level of screening is, you know that electrophoretic velocity would be depending on surface queue queue the charge on that particle; electrophoretic velocity will depend on the size of the particle on top of that, there would be another mesh sitting there, it will allow only particles of certain sizes, so that that that is referred as gel electrophoresis.

So, this is people who are students, who are connected with bio chemistry or bio chemical, those those sort of applications if you are working with, you will see this kind of gel electrophoresis it's very common. Anyway with that, I conclude the discussion on electrophoresis.

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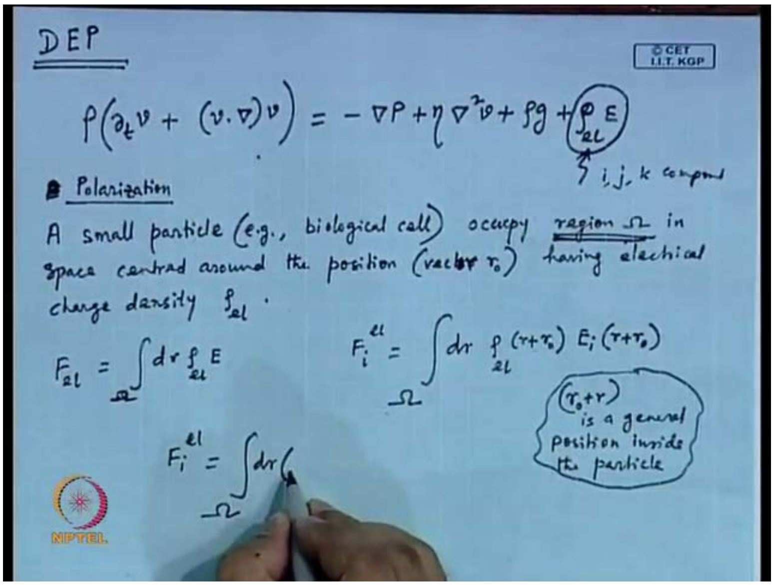

DEP

$$\rho\left(\partial_t v + (v.\nabla)v\right) = -\nabla P + \eta\nabla^2 v + \rho g + \boxed{\rho_{el} E}$$

i, j, k compont

Polarization

A small particle (e.g., biological call) occupy region Ω in space centrad around the position (vector r_0) having electrical charge density ρ_{el}.

$$F_{el} = \int_\Omega dr\, \rho_{el} E \qquad F_i^{el} = \int_\Omega dr\, \rho_{el}(r+r_0)\, E_i(r+r_0)$$

(r_0+r) is a general position inside the particle

$$F_i^{el} = \int_\Omega dr\,($$

The next topic that I pick up is, is is Dielectrophoresis I referred this is would be referred as DEP, Dielectrophoresis. And this is this is this is a different concept; it is it is not electrophoresis, not not an extension electrophoresis even it is it is it is a different thing. This, now before we before we get into this DEP, I would revisit I mean I keep writing this I have written it at least a two three times before, but still I mean let me, there is no harm in writing once again, I write this Navier-Stroke equation once again. (No audio from 27:08 to 27:37)

And let us, try to understand something called polarization process, which is known as polarization. What is this polarization? A small particle a small particle such as a biological cell occupying suppose this occupy, region omega in space centered around the position vector r 0 having electrical charge density rho e l. What we have now? A small particle such as a biological cell, occupy region omega in space centered around the position position is, position is position is is given by r 0, position vector is r 0 having electrical charge density rho e l.

So in that case, you have this as the body force term you you would be, you have considered before, where this rho e l and electric field E, their product, this is acting as a body force term in Navier-Stroke equation (Refer Slide Time: 29:46). Now, if we try to look at this body force term now, focus on this body force term.

Body force term will have, this will have i j k components and if we if somebody wants to write this body force term, it would be like body force term would be since we are talking about a region omega, then this should be generally there body force term would be, d r rho e l E for the entire region omega. So, that is that is what that is what the body force term would be defined in this case, since we are looking at a region omega and not just a point.

So, if we talk about the i th component then, this would be equal to (No audio from 31:01 to 31:20) this would be equal to, so what this would be, this this expression would be there, for the i th component of this body force term. So, you have a particle occupying a region omega, this is something which is new here.

So, if it is occupying a region omega around a position vector r 0, so for all such points around r 0, so what is what is r 0? What is r plus r 0 or rather r 0 plus r, what is this? This is a general, this is a general position inside the particle, inside the biological cell; inside the biological cell, there are several positions and those individual positions are given by r 0 plus r, r 0 is fixed because r 0 define the center of that region omega around that center, there are several r’s. So, you have to take into account them. So, this r 0 plus r is a general position inside the particle.

So, when we are talking about the i th component, we are talking about these E i all right. So, this is the expression for the force in the i’th component of it. Now this, if we if we go for a Taylor series expansion and and ignore the higher order terms. Taylor series expansion would be then, if i e l would be equal to this part remains same, let me use another slide.

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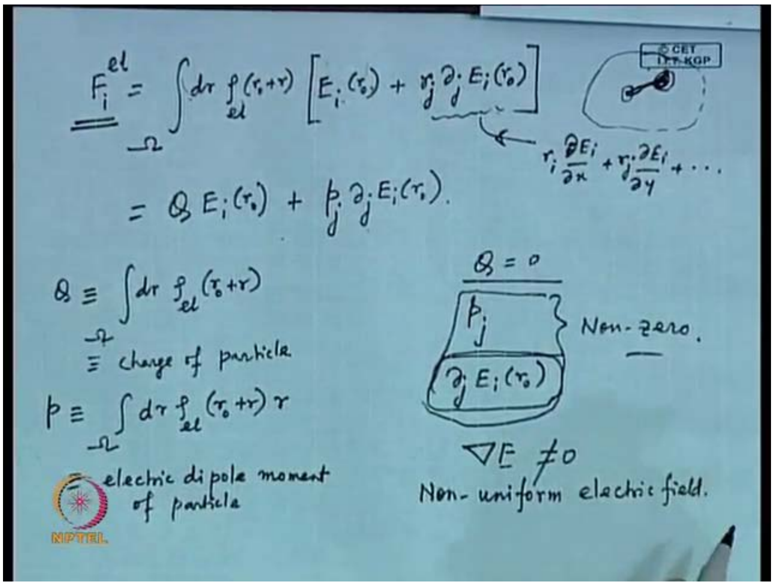

$$F_i^{el} = \int_\Omega dr\, \rho_{el}(r_0+r)\left[E_i(r_0) + r_j \partial_j E_i(r_0)\right]$$

$$r_i \frac{\partial E_i}{\partial x} + r_j \frac{\partial E_i}{\partial y} + \dots$$

$$= Q E_i(r_0) + p_j \partial_j E_i(r_0).$$

$$Q \equiv \int_\Omega dr\, \rho_{el}(r_0+r)$$

$\equiv$ charge of particle

$$p \equiv \int_\Omega dr\, \rho_{el}(r_0+r)\, r$$

electric dipole moment of particle

$Q = 0$

p_j, $\partial_j E_i(r_0)$ } Non-zero.

$\nabla E \neq 0$

Non-uniform electric field.

Taylor series expansion will give (No audio from 33:18 to 33:26) this part remain same, it remains unchanged, you are expanding the E term around r 0, around r 0 (No audio from 33:48 to 33:59). Do you let me let me let me write the next step also then, I will get back to how how we expanded this, (No audio from 34:08 to 35:14) will now this is this is the framework I mean we will get into this discussion later, do not do not do not bother about it. I said that I have made a Taylor series expansion of this term E i r 0, what does what does what does this term mean? I mean if we if we expand this term, how will it appear, it will appear something like this right.

For the (( )) components you you you have to you have to expand these E i r 0. So so what what exactly you are doing around point r, you are doing a Taylor series expansion of the field E. So, a general vector is r 0 plus r. So, from this point r 0 say, this is this is this is a this is a new, this is a different this is the local difference suppose, this is this is the region omega, this is the center r 0, around center r 0 you are expanding E.

So, any any other point r 0 plus r, if you try to find out what is the value of value of E at that point, you are using this Taylor series expansion for that purpose. So, you need to find out, so you you you have to take that first derivative of it del E i del x, del E i del y and multiply with the corresponding r right. So, that is that is what exactly what we are talking about here. It is a Taylor series expansion in a in a, which has more than one dimension. So, make sure that you you understand this and if we if we do not, then we can probably discuss this once again later.

So, basically we made a Taylor series expansion of this E term. What did we have earlier then, then it will be clear, what what did we have earlier? We were talking about this expression (Refer Slide Time: 37:17), F i e l is equal to integration this part remain same, this part we are not touching, this E i r plus 0. So, E i r plus 0 is expressed as, E i r 0 plus h f prime x plus h square by 2 factorial f double prime x that, that is what we are looking at.

Higher order f double prime x and all those are all neglected I mean h square term onwards neglected, only we are focusing on h f prime x. But, since it has multi dimension involved, so it would be it would be taking the shape of this (Refer Slide Time: 38:11), then you would be writing this.

So so you have two things here, one is this, this and this, you are clubbing them together and calling it Q E i r 0. What is Q then, Q is nothing but, integration d r rho e l r naught plus r, so you are clubbing this you are calling one, clubbing this two terms or this term another is this multiplied by this (Refer Slide Time: 38:35). So here, basically taking this third bracket off multiplying this with this, multiplying this with this, and you are getting these two terms here, one is Q E i r 0 and another is p j del j E i r 0, the derivative of it al right.

So, you have you have this these two term were Q is equal to integration d r rho e l r naught plus r and what is that now, that is referred as charge of the particle, no doubt about it, rho e l into rho e l d r, so you are basically summing rho e l over the entire region omega, so that is basically charge of particle.

And p is charge multiplied by the corresponding position, this is referred as electric dipole movement of particle I mean we do not need to get into the I mean we we can get into the definition of this later. But, one thing I want you to appreciate here is that, if the Q is Q is equal to, if the Q is equal to 0 if Q is equal to 0 if Q is equal to 0; if we look at the Navier-Stokes equation earlier (Refer Slide Time: 40:14), if Q is equal to 0 then, you would have called this, this term is is is not the I mean you have our understanding is Q is equal to 0 means what? Over this entire region omega, the net surface I mean what

what is Q, integration d r over the entire domain omega rho e l r naught plus r. So, sum of all the individual charged densities at various points.

And, if the net charge of that particle is 0 in that case, our understanding is that this is incapable of giving giving rise to anybody force, that is what our understanding was. Now, the point here what I am trying to make is that, I mean that is I am talking about a electric field, I am talking about a particle sitting there and within that particle within that entire omega, the net Q if I sum all those individual rho e l r 0 plus r, if we sum them over that entire omega, I found that that is 0.

On immediate conclusion is, there is no charge on this particle. So, this particle is not ready to give rise to any any any electric, any any any such body force electrostatic body force. So, we do not have that, we do not have to bother with this. The one catch here is that, this E term, the capital W we assume that, that electric field is uniform. But, what this analysis what what I am what I what we said here? This analysis says is that, even if Q is equal to 0, if p j and del j E i r 0, if these two terms are non-zero if these two terms are non-zero then, still there can be a body force F i e l possible, that is what this this I mean I am trying to drive at.

So, what does this mean that I have, p j a non-zero and and particularly what does this mean this term (Refer Slide Time: 42:34), do you do you do you have any idea what this is? What this means is that, the gradient of the electric field is non-zero gradient of the electric field is non-zero. Gradient of electric field non-zero means, delta E this is non-zero, and this delta E this is non-zero. Delta E is non-zero mean, the immediate response would be this is non-uniform electric field.

How do you get a non-uniform electric field? Do you I mean I am familiar with uniform electric field I have one, we have been discussing so far, so many drawings we made; one electrode here, another electrode there all uniform, if you draw the those lines, they are all straight lines right. How would you get a non-uniform electric field? If you can get, I mean the idea here is that, the what what the what the people are driving at is, if you can get a non-uniform electric field, there is still a force it can deliver, there still there is there is a force possible of course, still this p j has to be non-zero, they club together, they can give rise to some body force.

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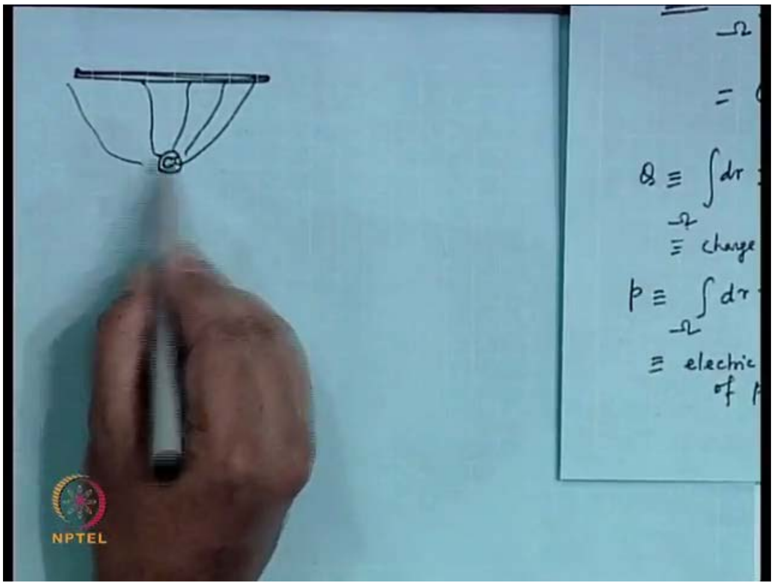

But, how will you get a non-uniform electric field? In this process in DEP, always DEP you will find, there would be two electrodes, one electrode would be planner electrode, another electrode would be a point electrode. There would be a planner electrode, so these would be the lines, so this is one electrode, this is the planner electrode and this is the point electrode, and that is how you create this non-uniform electric field.

So, non uniform first of all these you get, you get that is how we ensured that, this is delta E is non-zero number 1; that means, del j E i r 0 this term is non-zero and then, this p j term has to be non-zero, p j is what? This electric dipole moment of particle, this term also has to be non-zero. Then in that case, in that case you would be writing these F what what you want to call it, dielectrophoresis F DEP.

F DEP I think we will we will give a different, F DEP we will discuss in different context, but I can put it this way, it would be p dot delta E, this is the definition of the force in this case (Refer Slide Time: 45:37), p dot delta E exactly that is that is what we are talking about. Q is equal to 0 Q is equal to 0, so this is the term that is contributing to the force. And Q is equal to 0 means, this particle does not have any net charge this particle does not have any net charge, but still we can have, we can attract the particle towards one electrode or not, based on certain properties of that particle, particle may not have to have some charge on it.

So, this this DEP let me tell you, I mean before getting into this theories for that. This DEP is, there is a very common method I mean the common way of using DEP is, something called DEP trap. You have several particles flowing through the stream and you want to trap certain particles based on their properties.

And the particles, they may not carry net charge, net charge on the particle the Q is 0, the total charge on the particle is 0, but based on the properties of the particle based on the properties of the particle and you are intentionally creating a non-uniform electric field; by that way, you can basically impart some FDEP, you can impart some DEP force on that particle; and that force can act against the drag of the particle. This this Dielectrophoresis, this is employed to separate live cells from dead cells.

Suppose, somebody is doing an analysis of some say pathogen and it is, so it is flowing through micro channel and you want to know how much is the, first of all you want to separate the live cells from the dead cells; and want to know, which you which are really the active cells because, if you if you if you measure the number of dead cells they are I mean anyway they are dead.

So, if you want to separate if if you want to separate them, so based on the properties of the cells, if you see those properties of the cells changing if you see the property of the cell changing, so so you can based on that, you can trap the particle. That means, this particle when it is flowing through the channel it, if you have to it, so there is a drag force the particle is experiencing because, it is it is flowing through the micro channel. So, there is a drag force, this particle particle is that that is the fluid is imparting on that particle on that say cell, on that biological cell.

Now, you are imposing a DEP force on this, so you are acting against that drag force. Now, depending on the property of the particle, some particles the DEP force that you impart is more than the drag force. So, you retain that particle near that electrode, near the point electrode. So, you have a channel, you have on top of the ceiling of the channel is a planner electrode, bottom of the channel is a point electrode and you have other accessories down the downstream, upstream etcetera.

When the fluid with these say biological cells, they are flowing through the channel then, depending on the property of that cell, some cells are held near the electrode, some are not. So, that is that is one major, that is what this DEP is going to do then, that this DEP trap. Also, this DEP is used in context with field flow fractionation; that means this DEP; DEP force will be acting to settle the particle at certain level within the channel. So, that is that is another way this DEP can act.

Now, what we will be doing in in the next class is? We will be we will be discussing this, we we we will be we will be coming up with some understanding of, what should be the velocity of the particle? And given the properties of the particles given the properties of the particles and the velocity of the particle, what should be the velocity of the particle? That means, at what velocity this we we should have, what should be the fluid velocity such that you can trap, the certain particles with these properties.

So, we need some we need some theory we need to we need to understand, what should be the, how how we relate this DEP force with the drag force to come up with those understanding. So, that is that is something we should be looking at, in in in probably in in in next class we will we will I think in the next class, we will be able to do that. In the next class, we will be defining this, those those velocities and those theories behind, I mean how we can theories this this part, so that we will be looking at.

And and also we would be, I would like to I mean I will I will show you, which I mean what we have this we have this property called epsa. If possible when you come to the next class, you you study these these property epsa that that we have been talking about so far, what is what is this epsa? epsa of a medium, dielectric constant. What is this, what is this property? So, you you try to try to try to understand, because this is this is the property that would define, this is the property or rather the relative I mean we have we have dielectric property of two things involved.

One is dielectric property of the cell, another is dielectric property of the medium, within which the cell is flowing, and these two dielectric properties combined. They will determine, what should be the force, dielectric force on that particle. So, if possible when you come to the next class has some try to get some understanding of this property epsa, which we have been talking about so far. Because, this is this is this is going to be very crucial in this analysis. And keep this at the very keep this very clear let here the, Q is 0 this Q is 0.

So, you have when it the way we have defined is in Navier-Stokes equation, the conventional this body force term, there we have assumed that, there is a uniform electric field when we talked about this electro-osmosis and all this, we have talked about an uniform electric field and there is a rho e l present, and they have given a body force. Here, this component is 0 (Refer Slide Time: 53:30), so ideally this, this this there should not be any body force, but the body force is arising, because of that p term, not the Q term.

So, this this you have to have very clear in your mind that, unless you have a non-uniform electric field, the you are you are you cannot create DEP because your net Q is 0. And yes your your your your net Q is 0. So so that is that is that is very very very important in this context.

That, the other thing that I have been forgetting is that, the beauty of this method is, you can use the AC I mean, you do not need to need a DC supply. You can have you can have AC current, I mean the voltage can be in alternating mode as well. So, in that case, you if this if the liquid that has certain ions, that will not be affecting the process at all. I mean suppose we said that, deionized water and those charges etcetera we we have been talking about we have this we have this problem I mean we know this, that the medium should be totally inert a medium.

But here, in this case you can you can use an AC field as well, you can you can use an AC electric field; that means, the point electric field that means the point electrode and a planner electrode, you do not have to apply a D C voltage between them, you can use a AC voltage as well. I can I can I will probably give you some idea, if you impose AC voltage it will not affect much the process I mean it that it will be an different formula, but still this process will work.

And but, beauty of it is, if you use an AC field, then you do not expect the charges which would have been otherwise moving to the electrode, getting into the process of electrolysis and all those, those kind of concerns will be gone, if you use an AC field. So, that is that is the beauty of this this method. This is the very powerful method, we will we will get into this in the next class, thank you very much.