Transport Phenomena in Biological System

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Lecture - 50
Charge Flux

Welcome back today, let us begin chapter number 5 we have total of 6 chapters, chapter number 5, which is on charge flux. So far, we had seen mass flux of course, initially we saw some mass conservation then mass flux, momentum flux, thermal energy flux or energy flux with a focus on thermal energy flux and now charge flux.

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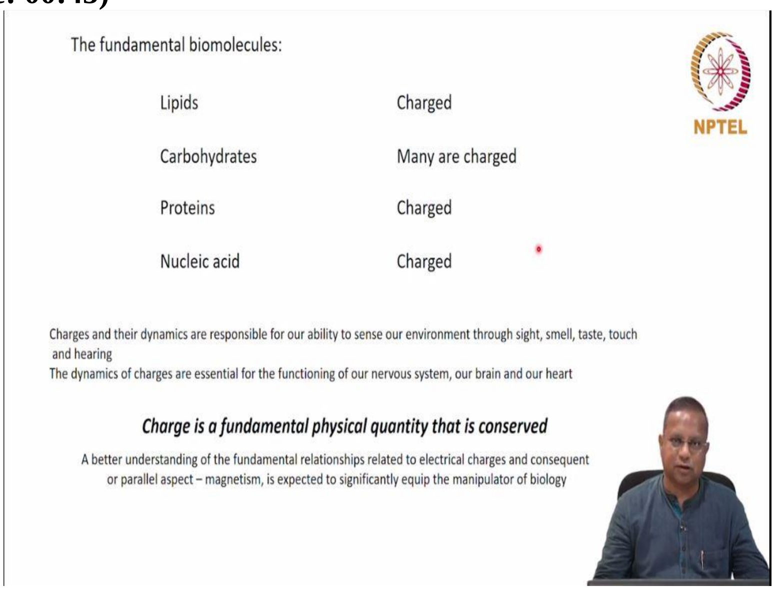

Why do we need to look at charge flux after all, not many engineers look at charge flux electrical engineers do but not many others look at charge flux as a fundamental aspect, but we need to why because the fundamental biomolecules that make up all biological systems are these you would have you recall this from your biochemistry course, lipids, carbohydrates, proteins and nucleic acids. These are the 4 kinds of biomolecules the fundamental biomolecules that make up only lipids are charged recall your cell membrane by layer lipids or other lipids.

They charge carbohydrates many are charged cannot all are charged glucose is not charged, but many are charged, especially the surface carbohydrates and so on they are charged proteins, they are charged proteins or polymers of amino acids, you would have an amino group a carboxyl group, peptide bond in between the amino acids that makes the protein and you have you could have charged groups on as they are groups and so on so forth.

So proteins are always charged. They are charged depends on pH and so on and so forth, yes, but they are predominately charged nucleic acids of course charged, remember the structure of a nucleic acid, sugar pentose sugar nitrogenous base and phosphate group. The depending on the type of sugar either ribose sugar or deoxyribose sugar you had either RNA or DNA and you have phosphate group there you have the nitrogenous base, they are full of charges. So, these are charged.

So fundamental biomolecules have charged therefore, biological systems are charged. Therefore, not just that the charges and the dynamics are responsible for ability to sense our environment through our various senses sight, smell, taste, touch and hearing, we will see some of this in the next chapter. The basis of this in the next chapter, the dynamics of charges are essential for the functioning of our nervous system, brain our heart and so on.

So it starts affecting at the base level, very fundamental level. So, charge is a fundamental physical quantum and also charges a fundamental physical quantity that is concerned. So a better understanding of the fundamental relationships related to electrical charges, and consequent of parallel aspect magnetism. The better understanding is expected to significantly equip the manipulator of biology.

And that is the reason why even undergraduates need to be comfortable with charge flux aspects in biological systems. That is an essential aspects to understand to effectively manipulate biological systems.

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So, let us start with some of the formulations that are centuries old in electricity, electromagnetic theory electromagnetic aspects and so on. So, some fundamental visualizations when, which have existed for centuries is that the space between interacting charges can be considered to be influenced by the charges. This was what was mentioned by Faraday. And recall what we talked about when Faraday was researching into this.

The one of the politicians of that time came and asked him what is the point in doing some white elephant kind of work? Ivory tower kind of work. Imagine electricity being called an ivory tower. Have pretty much nothing to do that you can I mean you cannot think of a life without electricity nowadays. So, that is what happens you need you should not neglect the fundamental aspects they would have a non significance over a very long term.

So, you need to give it due respect and due care and so on. So, the forces between 2 charges let us say 2 charges are transferred from one charge to the other through the space in which they are located. This is the picture which helps understand electrical aspects and magnetism aspects. The force between say 2 charges are transferred from one charge to the other through the space in which they are located.

Therefore, electric and magnetic fields the region of influence exists at a point in space even in the absence of actual charges at that particular point, this is worthwhile understanding in great detail, electric and magnetic fields, fields are nothing but the space where there is influence. Fields exist at a point in space, even in the absence of actual charges at that particular point. There is a fundamental view of charge.

Now, let us consider the effect of those fields on a charged particle and the force experienced by that particle. So, you have a field you have a charged particle, we are looking at the force that is experienced by the particle. Can you recall? What is the force sense experience with a particle you have already seen this I am sure you would have seen this is a part of your physics course at higher secondary school level or at the first year level of your engineering correct.

Can you recall what that is what is the effect the force experienced by a charge particle when it is in the presence of electromagnetic field pause go back check concern if you need that is given by the Lorentz force law.

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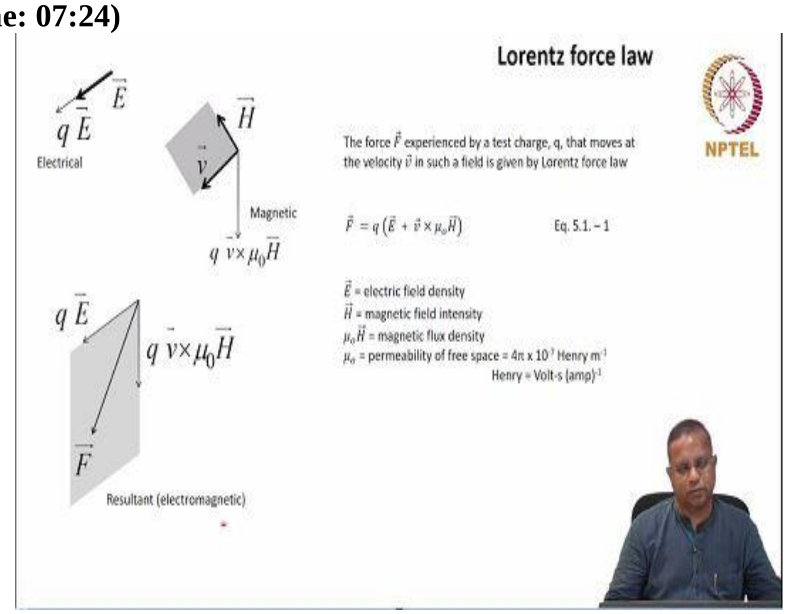

The charge experience the force experienced by charged particle in electromagnetic field is something like this, we need to understand this clearly. Therefore, let us reveal certain things that you know already. Maybe you do not know at this level of clarity and so on, but a high clarity is needed for us to understand these electrical aspects also. The force F experienced by a test charged q. That moves at the velocity v in such a field is given by the Lorentz force law.

You know, the force experience by electric charge that moves with a certain velocity in electromagnetic field is given by

The force $\vec{F}$ experienced by a test charge q that moves at a velocity $\vec{v}$ in such a field is given by the Lorentz force law

$$\vec{F} = q(\vec{E} + \vec{v} \times \mu_o \vec{H}) \tag{5.1-1}$$

where $\vec{E}$ is the electric field density, $\vec{H}$ is the magnetic field intensity, $\mu_o \vec{H}$ is the magnetic flux density and μ_o is the permeability of free space $= 4\pi \times 10^{-7}$ Henry m^{-1}, Henry = Volts $(amp)^{-1}$.

recall the Lorentz force law equation 5.1 - 1 where E is the electric field in density H is the magnetic field intensity μ_0 exists the magnetic flux density these are the terms by the way in electrical engineering the terms will be slightly different especially fluxes used in a slightly different context do not get confused between that and this I will I have taken enough care to distinguish between those.

But just keep in mind that when you see flux from a point of view of electrical aspects you need to make sure what you are talking about because the historical development has given a slightly different meaning to flux then what we understand flux as in this course. Because metabolic flux is nothing but metabolic flux was nothing but a metabolic rate in this case they mean something else and so on and so forth. We cannot erase history we cannot erase how they have been used for a long time.

So, we just need to get used to that without confusing our usage with this usage μ_0 of course, the permeability of free space the values $4\pi * 10^{-7}$ Henry per meter these are the units this is some kind of a review for you. So, go back and check your high school first year notes to understand these better or textbooks. Henry is volt second per amp. Now, if the electric field is E the electrical force on the charge particle with the charge q, it is charge q is qE it will be in the same direction as that of the electric field.

The, if the magnetic field density is μ_0 H magnetic field intensity is H. If we consider the plane of the velocity and H to be something like this, then the magnetic force would be in the direction that is perpendicular to the plane that contains v and H, there is a certain velocity there is a certain magnetic field intensity, you can form a plane with those and the magnetic force is going to be perpendicular to that plane.

That is what is indicated here qv $\times \mu_0$ H so these are vectors is in a direction the cross product would automatically give you this as the direction of the force. So, you have the electrical force here you have the magnetic force here. And therefore, the total will be in this plane that contains q E and the magnetic force qv $\times$ μ_0 H these 2 if you consider as a plane, the resultant force is going to be this way.

So vectorial some of qE, and qv $\times$ μ_0 H would be the resultant electromagnetic force on a charge q moving at a velocity v remember this I hope you have got the directions fine. If not, you go back and revisit this let me very briefly mentioned again, what we said this the electric field E, the electric force will be the same direction as electric field E the magnitude of that will be q times E, the magnetic field would be in a direction that is perpendicular to the plane that contains the velocity and the magnetic field intensity.

These value of the magnetic force would be q times v$\times\mu_0$ H. And what we are interested in is the resultant force of the electric force and the magnetic force. So, if we consider the plane that contains electric force and the magnetic force knowledge that there are these are 2 vectors, you can construct a plane there, in that plane, you will find the resultant force and of course you can find out the vector some of these 2 that would be the direction and magnitude of the resultant electromagnetic force.

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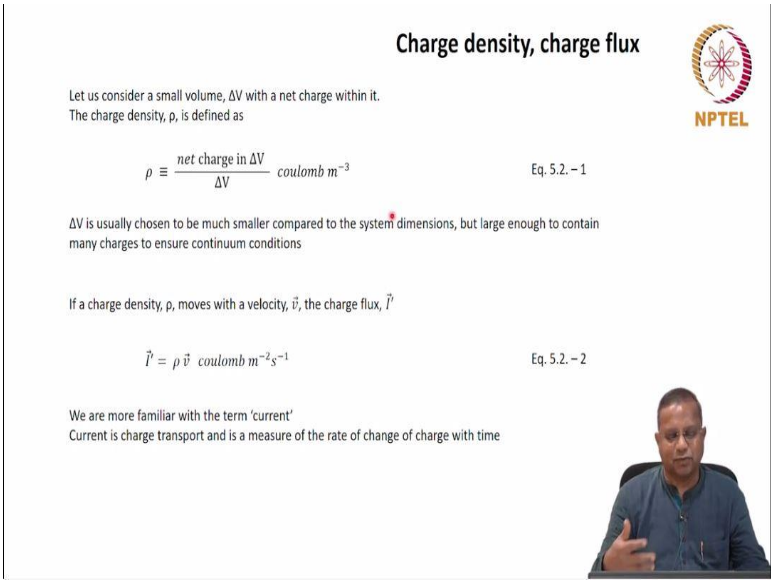

We need to get a review or get used to some terms charge density and charge flux. Charge density is quite straightforward. Let us consider a small volume Δv enabled concept small enough for something large enough for something else. So, let us consider a small volume Δv with a net charge and with a net we always look at net charge by the way everything relates to net charge which is sum of positive and negative charges put together.

If we consider a small volume, ΔV with a net charge within, the charge density, ρ, is defined as

$$\rho \equiv \frac{\text{Net charge in } \Delta V}{\Delta V} \text{ coulomb m}^{-3} \qquad (5.2\text{-}1)$$

Equation 5.2 - 1 this is charge density with straightforward quite intuitive charge flux again before that, let me re-emphasize that Δv is chosen to be small enough compared to system time dimensions.

but large enough to contain many charges to ensure continuum conditions some sort of enabled concept that we saw when we looked at turbulent flow and so on and so forth also. So, our species concept there this is very similar to the species concept in the volume much smaller compared to system dimensions, but large enough to contain many unitary aspects in this case charges to ensure continued conditions.

If a density if a charge density ρ moves with the velocity v, the charge flux I -, note I am calling this I’ as charged flux, because i is reserved traditionally for a different quantity. We will see that later.

Current is charge transport and is a measure of the rate of change of charge with time. If a charge density ρ moves with a velocity $\vec{v}$, the charge flux $\vec{I}\,'$ is denoted as

$$\vec{I}\,' = \rho \vec{v} \text{ in coulomb m}^{-2}\text{s}^{-1} \qquad (5.2\text{-}2)$$

So, charge flux I’ equation 5.2 - 2 we are more familiar with the term current and current is nothing but charge transport and is a measure of rate of charge with time. There is no area aspect here and we are going to retain the symbol I for that. And that way will be in line with the traditional use of I. So, I am going to call this as I -. By the way, the development here you would not find in any book except mine and also in some of the development you would not find.

Especially the derivation of the charge conservation equation you will not find. And also the derivation that I am going to give you here is different from the one that is there in the book. Not that the book was written 10 years ago. Subsequently, I have been teaching this course ever since and even before that, and I found more direct ways of telling you things without you are confusing students. So I brought him that entire experience into this course. So whatever you are getting is years of experience so that you will find it much easier to fall.

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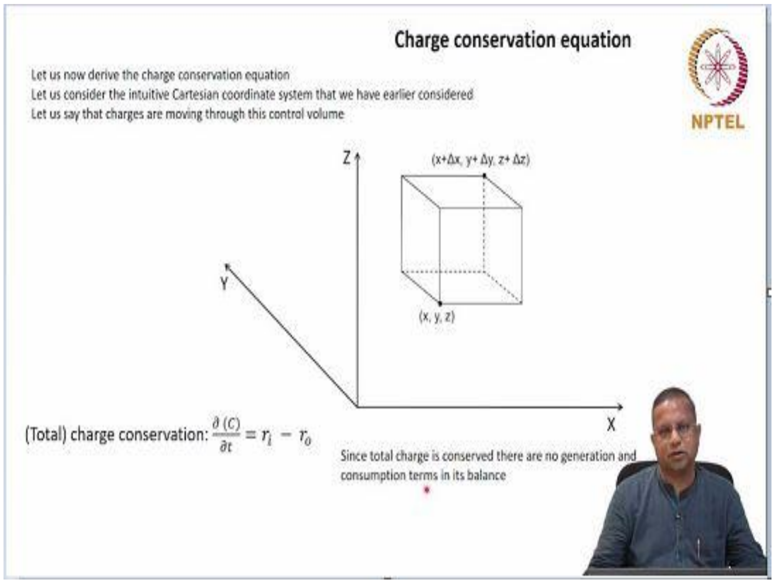

Now the charge conservation equation, this is what I meant. This is not there in my either any book or my book. This is a part of this course, for the outside world. I have been teaching in this way for many years now. Once I realized that you could do the same conservation aspects as we did for mass momentum energy and come up with the same charge. Now, let us derive the charge conservation equation, we have derived the mass conservation equation, we have derived the momentum conservation equation.

Then the energy conservation equation now the charge conservation equation let us consider the intuitive Cartesian coordinate system that we have considered earlier. Let us say that the charges are moving through this control volume in 3 dimensions. So, the same thing X Y Z this is X Y Z and X + ΔX, Y + ΔY, Z + ΔZ and charges are moving in all 3 directions. The total charge conservation is similar to total mass conservation input minus output because charge can neither be created nor destroyed.

So, we are looking at total charge no negative no positive separately total charge. So, $\frac{\partial c}{\partial t} = r_i - r_o$, c is charge and total charge is conserved and therefore, there is no generation or consumption term in this balance.

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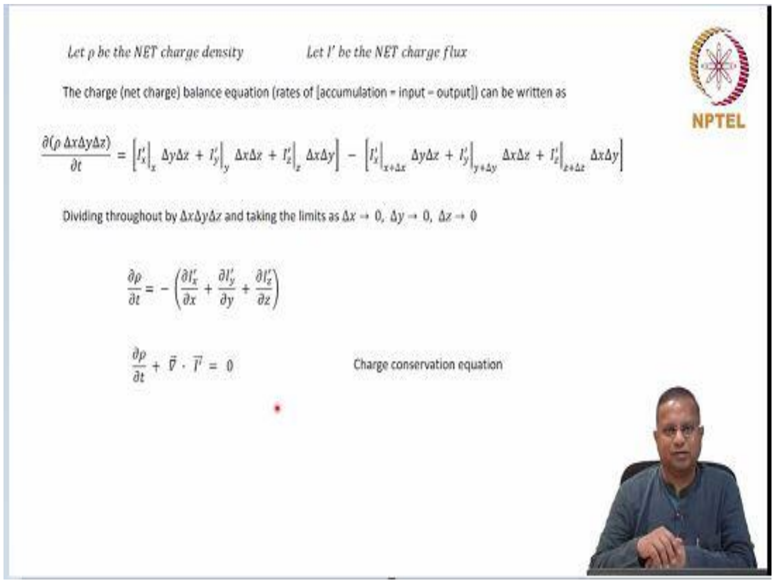

Let ρ be the NET charged density this you should internalize its NET charge density. Let I' be the NET charge flux amount charged transferred per unit time per unit area perpendicular to the direction of transfer and the net charge balance equation. This becomes accumulation equals input minus output as we have already seen here. This is input minus output. So, the net charge can be written as NET charge density times of volume.

Let ρ be the NET charge density. Let I' be the NET charge flux.

$$\frac{\partial \rho\Delta X\Delta Y\Delta Z}{\partial t} = |I'_x|_x\, \Delta Y\Delta Z + |I'_y|_y\, \Delta X\Delta Z + |I'_z|_z\, \Delta X\Delta Y\, |- I'_x|_{x+\Delta x}\, \Delta Y\Delta Z + |I'_y|_{y+\Delta y}\, \Delta X\Delta Z + |I'_z|_{z+\Delta z}\Delta X\Delta Y$$

$$\frac{\partial \rho}{\partial t} + \nabla\, I' = 0$$

So, this is something that I had developed with inputs from one of my students was bright, they by he had provided the initial things. He tried to write it in a different way and based on that, I had developed this I would asked him to develop that because he was he could see things clearly. And then he wrote it in a different way because they consider negatives and positives separately and so on so forth. We need to look at net charges and this comes out in a very, very small number of steps.

I think we need to stop here. There are a lot of basics that we need to be become comfortable with. So partly review partly new kind of a mode we are going to be in in the next class also. See you in the next class. Bye.