Introduction to Complex Biological Systems
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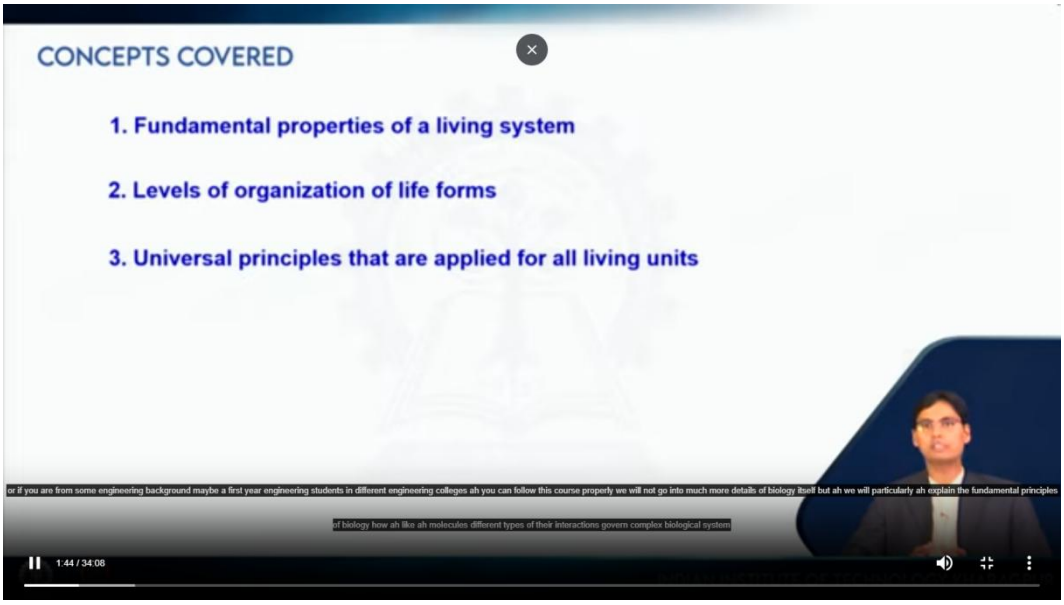
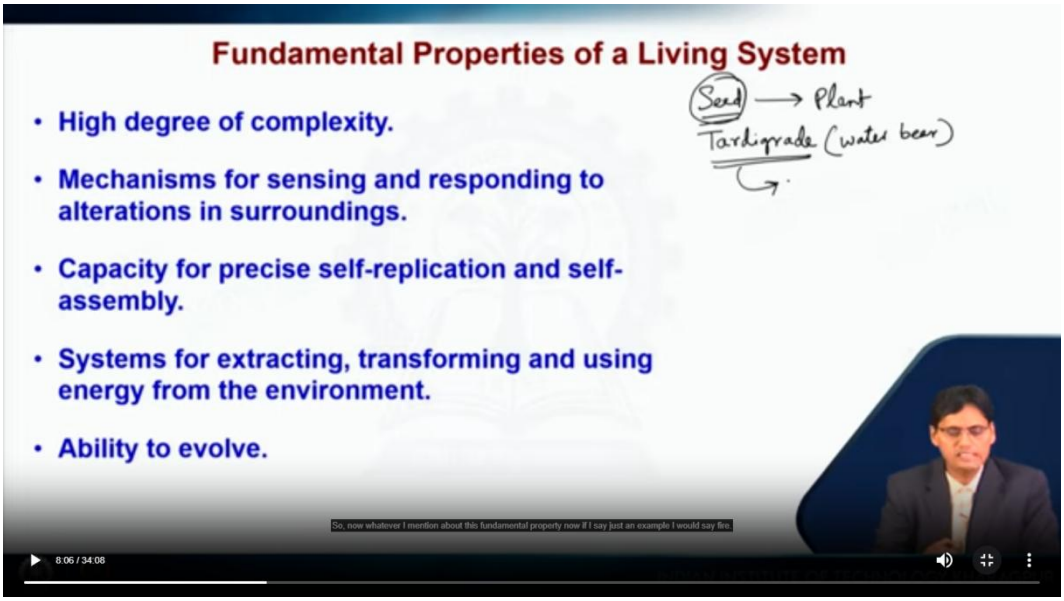
Lecture 1
Fundamentals of a Living System

Thank you very much. Welcome to online NPTEL course on Introduction to Complex Biological System. I am Dibyendu Samanta, a faculty member in the Department of Bioscience and Biotechnology at IIT, Kharagpur. So, today I will start the module 1 nucleic acids, the hard drive for the information of life. So, today this is just introductory topic.



So, here I am going to discuss about fundamentals of a living system. And this will be a short lecture, where I would like to particularly explain the fundamental properties of a living system and level of organization of different life forms followed by universal principles that are applied for all living units. So the course is designed in such a way that students from different background, you can be from biology major, or if you are from some engineering background maybe a first year engineering students in different engineering colleges, you can follow this course properly. We will not go into much more details of biology itself but we will particularly explain the fundamental principles of biology, how molecules different types of their interactions govern complex biological system. So, therefore, it will be interesting for all of us whether you have some good background in biology or not that does not matter too much.



So, here fundamental properties of a living system, if I try to explain what is a living system. It is very difficult to define. What is life? Sometimes it depends on to whom I am asking this question or who is answering this question. Because, you know, it is really difficult to understand what is life.

Say, for example, if I say a seed, lying on a floor. So, apparently it seems like it is nonliving thing, but all of you know that when this seed properly gets suitable conditions, I would say some water, air and soil then it will germinate and it will give rise to a plant. So, I cannot say that seed is a nonliving entity, seed has life, but maybe it is in different condition, maybe it is dormant, but some basic level of metabolic activity is still going on inside the seed and whenever it is getting suitable condition, it will germinate and give rise to a plant.

Similarly, a seed is very common, all of us know, but sometimes if I give you another example. For example, a Tardigrade, this is an animal, I would say this is a millimeter-long cousin of arthropod, it is very small, but you can you compare with some something like arthropod like cockroach and its common name is water bear. The beauty of this animal is that it can stay for long time, I would say not just few months, years after years like in a very difficult condition, very high temperature, for example 100 degree centigrade temperature or without water for 100 years, no problem it can still survive whenever it will get proper environment and optimal condition again it will be in its proper form, it can again work, it can go from here to there. So, as a result of that understanding the chemistry, understanding the mechanism, how Tardigrade actually maintain this property in a harsh condition. It can be just staying as nonliving stuff, but actually life is there and in proper condition it can go around and it can up be showing it that this is alive. So, let us discuss about those fundamental properties rather than defining what is life.

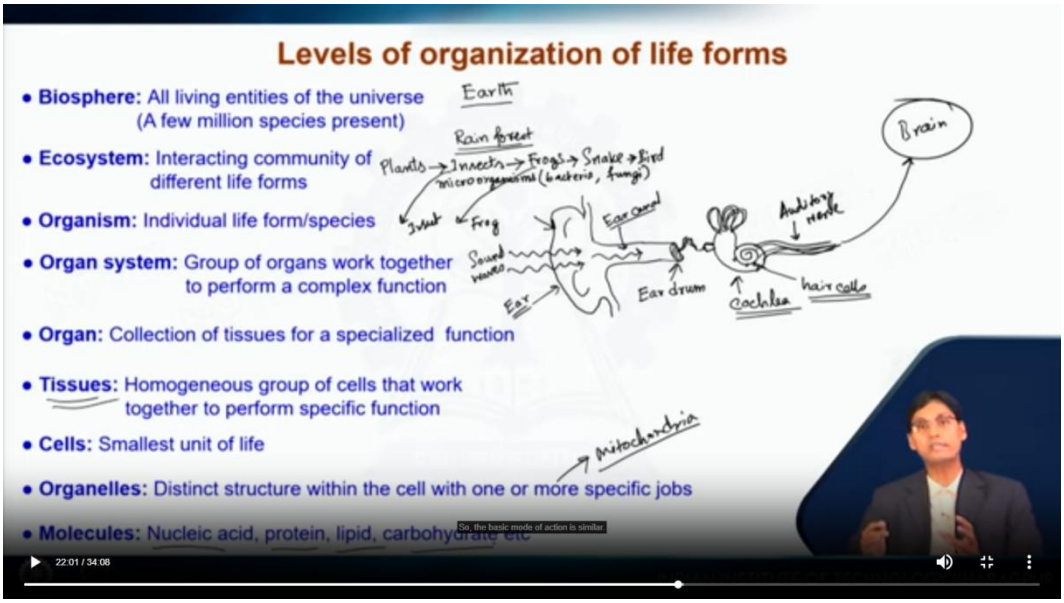
So, first of all it is very complex thing, high degree of complexity should be there in a living system and then mechanisms for sensing and responding to alteration in surrounding this is also true for all living entity. For example, as I mentioned that seed whenever we are giving some condition, for example water then seed will germinate so it can actually respond in alteration of surrounding and then capacity for precise self-replication and self-assembly.

This is very important because any living entity, any living unit will try to make its offspring so that the line can survive. So, they can make their own entity and then system for extracting, transforming and using energy from the environment. So apparently you may think that we are not really extracting and transforming energy from the environment, but actually we are depending on some other organism, for example, plants. All of you know that plants, they can do photosynthesis in presence of sunlight and they can trap carbon dioxide from air and taking water from the soil and they can make food like particularly carbohydrates. But those foods are being again utilized by us, animals and many other organisms.

So as a result of that, living entity, they have systems for extracting, transforming and using energy from the environment. And then ability to evolve. This is very important thing. The living system, they can evolve over time. Like, you know, over millions of years living system, they actually, you know, evolve in such a way that they have solved many of the problem.

So that's why ah nowadays there is another subject which is, very, I would say, interesting and coming up that is called biomimicry or biomimetics. where like human being for example, we try to understand from the nature particularly living units they have already solved many problems so if we can study living thing properly and then we can actually take those information and try to design something, try to make something that is why biology is very important and you can understand that biology is being taught everywhere. Now for all engineering college, mostly in their first year they have some kind of fundamental biology course. So, now whatever I mention about this fundamental property now if I say just an example, I would say fire. So see I discuss about seed, I discuss about Tardigrade now I am saying fire.

So all of you know fire, fire is a nonliving thing. But see now, like almost all of the properties, whatever I discuss, everything like you can see in fire also. Like they can be complex and they can sense and respond to alteration in surrounding. For example, if you give more air, more oxygen, fire will grow. and they can also replicate fire can actually multiply and also they can extract and transform energy from the environment so as a result of that that's why at the beginning I told it's very difficult to explain what is life and what is living system, but all together if we understand all this property and I will discuss some more thing then you will be able to understand what is a living system and what are the fundamental properties of a living system.



Now, I will go into the next part, the levels of organization of life form. I understand you know that there are several types of living unit present in earth, but we would like to summarize them in terms of their organization. So, if I start from the very beginning I would say for example, biosphere means all living entities of the universe. So, a few million species present in universe. So, everything together we would say that this is biosphere. So, now if I give an example of biosphere. So, I would say earth Earth is an example of biosphere. So, we are many different types of living entity present. Now, maybe some other planet they might have living entity, but we are not aware yet. So, that is why I am just giving example that earth is an example of biosphere.

Then ecosystem. So, ecosystem means the interacting community of different life forms. So, as a result of that I would say there are many ecosystems present in biosphere and ecosystem means I would say for an example like rainforest ecosystem. So, rainforest ecosystem is very common in our country i.e. in tropical country. So, now in rainforest ecosystem if you see in forest you have different types of plants, it can be trees, it can be some small grasses. Now there are insects they are depending on this plants they are eating some of those plants. So, now some other animal for example frogs they can depend on insect and then followed by snake and birds. So, all those living entity they are depending on each other and at the end I would say they will die also at some point of time. So, we have also microorganism that means I would say microbes it can be bacteria, and many more microbes.

So, they will again destroy these dead body of this snake and birds everything and again it will be recycled. So, this is ecosystem and now if we go to the next level organism the individual life form or species present in this biosphere or present in this ecosystem whatever you say this is organism. For example, an insect is an example of organism or frog, insects those are organism present in biosphere.

And now if we go to the next level then organ system. Group of organ work together to perform a complex function that is called organ system. So if we say organ system, for example, in human body, there are different organ system present and if I say our digestive system, this is an organ system because many organs, they work together to do particular type

of job. For example, we have stomach, we have intestine, large intestine all together they form this digestive system and they digest our food, when we eat food they digest it together. And now the next level if we go again it will be organ that is collection of tissues for a specialized function that is called organ and we have different types of organ in our body. So, if I explain like I started from biosphere and I will go up to molecule level just to explain the different level of organization.

So, here if you see I am just trying to draw some organ here. So, now you can understand. So, this is our ear. human ear, so this is an organ and ear is very important for hearing as well as for balancing, both function actually carried by our ear and now if you see inside organ we have different types of tissues for a specialized function. I will explain you whenever time will come. Now tissues, these are homogeneous group of cells that work together to perform specific function so I will explain this organ and pieces together in context to our ear, so now if this is an ear so and we hear through our ear, so what happens when sound waves enter inside our ear. So, we have external ear and this is called ear canal, sound wave is going through ear canal and then at the end of the ear canal, you have a thin membranous tissue. We have thin membranous tissue which is known as ear drum.

So, it has some specific function and it has some specific type of cells. So, for example, when we beat a drum, what happens? It vibrates and it makes some sound. So, similarly when the sound waves that enter through ear canal, it hit the ear drum, the membranous tissue there as a result of that ear drum actually vibrates and that vibration is going through different parts of the ear which is present in middle and inner ear and accordingly everything happened properly and we can hear. What is happening here? We have small bones, tiny bones present just after the eardrum. So, they can also vibrate. So, as a result of that, this sound waves, this sound gets amplified and it reaches into the next level through the middle ear or through this tiny bone. So, in the inner ear, we have a different structure called cochlea, this is present in inner ear. So, it has also some specific type of tissues, they have some specific function. So, as a result of that now this sound waves reaches into this cochlea and this cochlea is filled up with some liquid. And as a result of that, the liquid present inside cochlea, that will ripple, that will make some kind of wave inside the liquid. And there you have some cells, specialized cells. Those cells are called hair cells. hair cell those are present in cochlea and because this liquid present inside cochlea, that is making some kind of oil and this hair cells also get some kind of motion. And because of this motion they will actually convert this mechanical energy into some electrical energy.

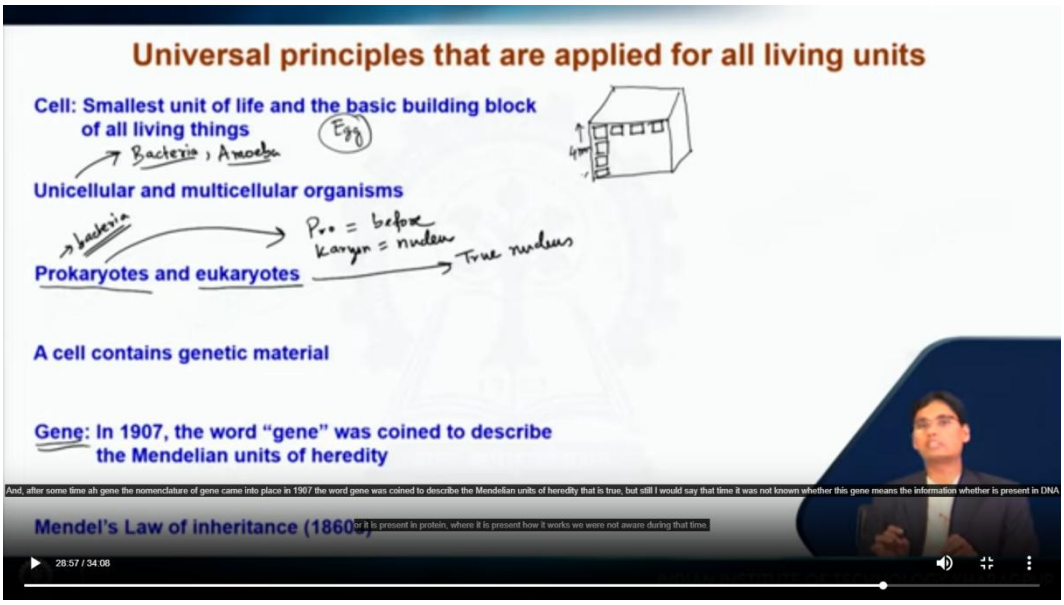
Some receptors are present in this hair cells. I am not going into that much of details and some nerve ending is also present. So, as you can see some nerve is going like this together, we say this is auditory nerve. So, as a result of that this mechanical energy that movement of this hair cell that is converted into electrical energy and that is going through our auditory nerve through into our brain and our brain can process this information as and we hear that sound. So this is all about the hearing process like briefly I just explained. But now what I want to mention that this is an organ this ear and now this ear drum it has specific type of cells which is a fissure then cochlea that is another type of fissure present in cochlea and now if we go to the next level the cell the smallest unit of life. So, cells are present everywhere, ear drum they have cells, cochlea they have cells, for example, hair cells and specially those cells if you see the fundamental mechanism going on inside the cells they are very similar to

each other. Although the function of eardrum and the function of hair cells are different, but at the cellular level, their activity is very similar to each other. And then we have organelle.

Organelle means the distinct structure within the cell with one or more specific job. So, if I give you some example of organelle is mitochondria. So mitochondria is an example of organelle and it is present in every cell. It is present in ear drum cells, it is present in hair cells everywhere and it is producing energy for us. So as a result of that, this is not just mitochondria, there are many organelles which are present, you know in all those cells and their basic mode of function is similar.

And I would say, in the lowest level, the molecular level we have some macromolecules, some biomolecules like nucleic acids, protein, lipid, carbohydrate those are also known as building blocks of living system and all together they made this kind of organelle. In this course, specially, we will discuss about the bottom half particularly from this molecules, organelles, cells, this was up to that, we are going to discuss about biosphere, ecosystem, organism, organ system because see in our world we have different types of biodiversity, different types of organism present. You will see lot of diversity, they are different from the outside they look very much different, but if you see at the molecular level, if you see at the cellular level, they are very similar.

Even I would say plants, bacteria or animals, human. So, the basic mode of action is similar. If you see at the molecular level, they are very close to each other. So, we are mostly focusing on this basic understanding, the fundamental understanding how this life form work in this course.



Now, I would like to explain the universal principles that are applied for all living. So, first of all, I already mentioned that cells, they are the smallest unit of life. So, and they are the basic building block of all living things. So, now why cells are small although some cells are big for example, like many eggs, particularly egg of bird and sometime eggs of fish those are kind of really big particularly eggs from bird like chicken egg for example, it is just a single

cell, it is very big for a different reason, but otherwise most of the cells are very small and cell should be small there are like a lot of advantage. If I particularly like particularly try to explain you why cell should be small. So, if I say this is one cell and here every side is 4 millimeters.

And now you will get some kind of surface by volume ratio. Now if I put here small small block here, so like this. Now also in this volume it is fitting, right like 4 cells here like this. Now if those cells are those units are very small then you will get in the same volume you have more surface. So, as a result of that if cells are small then the surface by volume ratio is increasing, which is very important because you know that for living thing, for example cells, they need nutrient, they need to exchange different types of gases. So, as a result of that if surface is more then all these exchanges of nutrients and gases will be much easier. So, that is why a small cells are always useful for us. And now if you see the next thing I am going to discuss about the different types of organism. For example, the unicellular versus multicellular organism.

Like there are many unicellular organism. So, if I give you an example that is bacteria this is prokaryote, I will explain what is prokaryote but this is unicellular bacteria and then some other organism for example amoeba this is also unicellular and then multicellular, all of us know for example human being, plant, we are multicellular organism but if you see whether it is unicellular or multicellular they have like various similarities at the cellular level and they have their own information in terms of genetic material and they properly function and that is why all of them, this living entity, they perform their specific job but the thing is all of them, whether it is unicellular or multicellular, they are very complex.

Even a bacteria is very complex. Because, for example, you know that bacteria, sometimes they develop antibiotic resistance. Although they are just unicellular, they have just one cell, right? But still, over the time, they can develop some kind of resistance against some antibiotic. And this is a big problem in human society, that antibiotic resistance in bacteria.

And then, we have prokaryote and eukaryote. So, if we try to explain this prokaryote, pro means before and karyon means nucleus. So, prokaryote means before nucleus and what is the example? I would say example is bacteria.

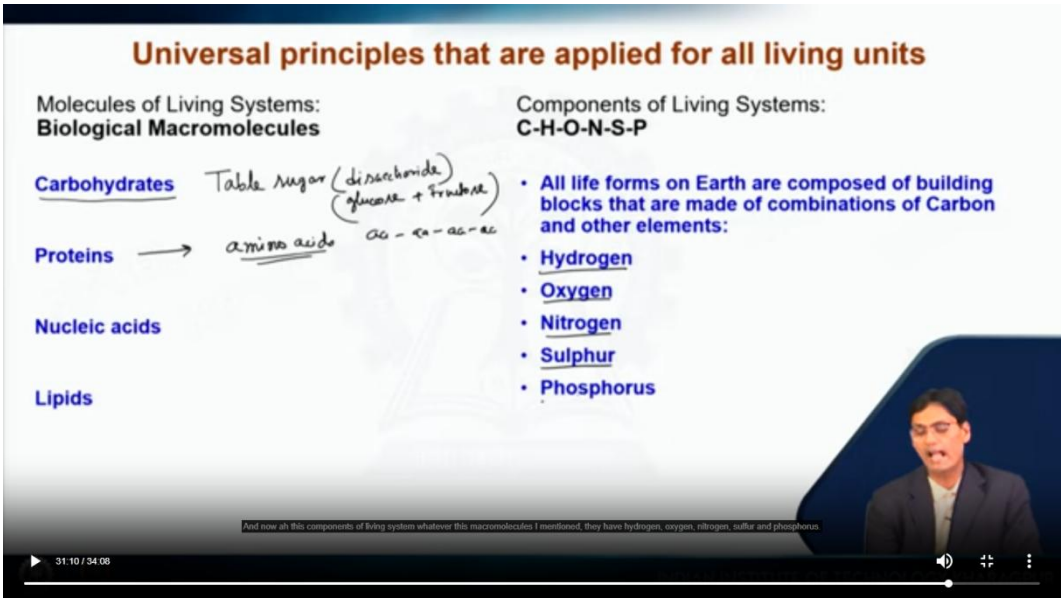
All bacteria, they are example of prokaryote. That means, they do not have nucleus. This is before nucleus. They do have genetic material, but they do not have nucleus. But in case of eukaryote, so eukaryote means, you mean true and karyon means nucleus. So, they have true nucleus. Nucleus is an organelle present inside the cell and inside that organelle, we have our genetic material. So, for example, a mouse, human, plant all are example of eukaryotic cell. So, again both bacteria and human like prokaryote and eukaryote they have their genetic material inside the cell.

And, as I already mentioned, whether it is unicellular or multicellular that does not matter, whether it is prokaryote or eukaryote that does not matter, all cells they have their genetic material. Since, I started talking about genetic material we should mention what is genetic material. So i will explain in more details in the next lecture but the thing is that all of us we know that Mendel's law of inheritance in 1860's, during that time Mendel discovered so many things, like which is actually coming from the previous generation to the next generation and based on that he properly explained that law of inheritance but at that time it was not known

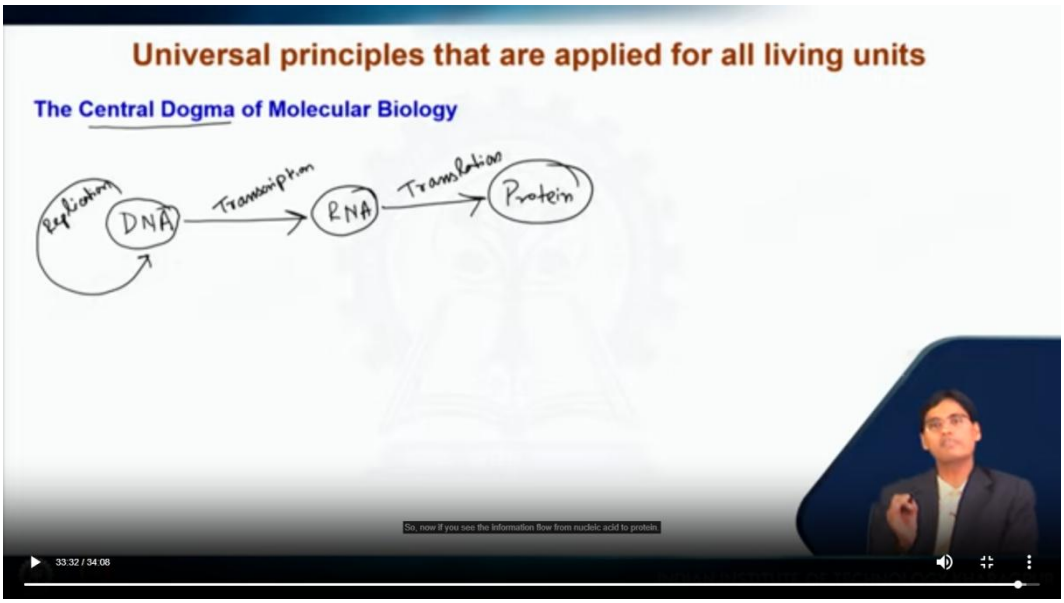
like how, what is the mechanism, where is this information is present, where the genetic information is present and how it is going to the next generation. The specific molecular mechanism was not known and after some time gene the nomenclature of gene came into place in 1907, the word gene was coined to describe the Mendelian units of heredity, that is true but still I would say that time it was not known whether this gene means the information whether is present in DNA or it is present in protein, where it is present how it works, we were not aware during that time.

And now again I would like to explain little bit about the macromolecules, like biological macromolecules for example, carbohydrates, proteins, nucleic acids and lipids these are again present in all living entity and all of them, they are kind of polymer. For example, if I say carbohydrates, it is present everywhere. So, carbohydrate, if I say just an example of table sugar, the sugar generally we use when we make tea or coffee. So, this is an example of disaccharide, that means two carbohydrate units are attached together. So, here glucose plus fructose. So, those these are the monomer they are attached together and they form stable sugar. Similarly, proteins they are made up of amino acid. So, amino acids are attached through peptide bond and they make this polymer.

Nucleic acids they are also polymer of nucleotides. So, as a result of that if you see this biological macromolecules, their basic structure is same, whether you are taking a protein or nucleic acid or carbohydrate from bacteria or plant or from human, that does not matter, but their basic architecture is same.

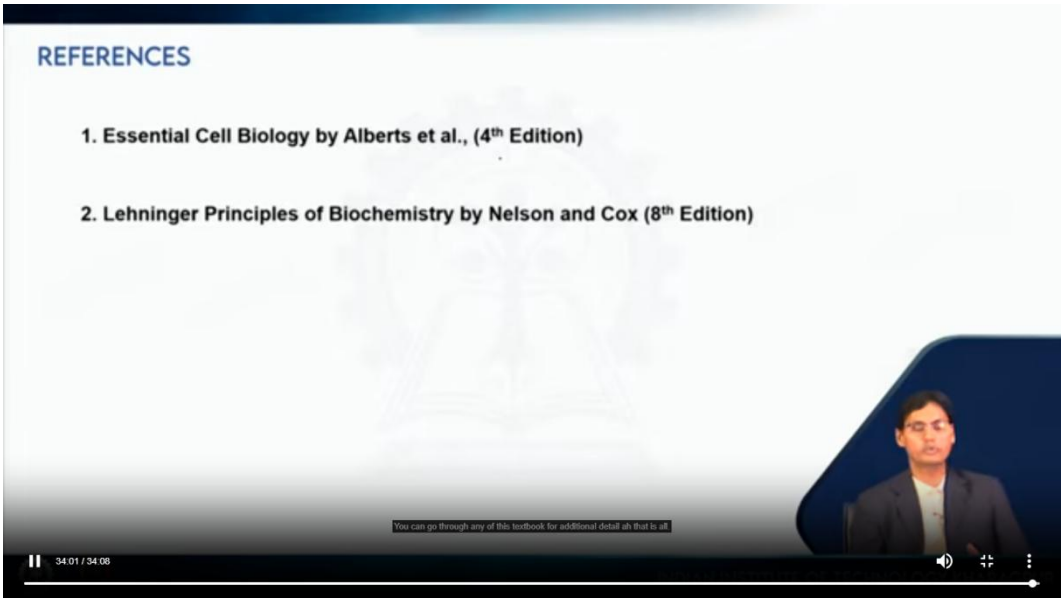


And now this components of living system whatever this macromolecule I mentioned, they have hydrogen, oxygen, nitrogen, sulfur and phosphorus. These are the major atom present in this biological macromolecules. Basically you should know that this hydrogen, oxygen, nitrogen and sulfur this is present in proteins and similarly hydrogen oxygen nitrogen and phosphorus this is present in nucleic acid. So, this information will be helpful in future discussion. So, as what you can see here that sulfur we are putting in protein and phosphorus we are putting in nucleic acid, but other three like hydrogen, oxygen, nitrogen that is present everywhere in nucleic acid as well as a protein. But I forgot to mention here one thing that is present everywhere that should be carbon.



This is the last slide for today's lecture that the universal principles that are applied for all living system that is central dogma, central dogma of molecular biology. I will discuss in more details in future, but if you see I just mentioned that all living entity they have their

genetic material. mostly I would say DNA is the genetic material in some viruses although RNA is present as their genetic material but that is some exception so DNA is our genetic material. Now DNA goes to DNA can make DNA right and this process is called replication and then DNA form RNA this is another polymer which is made up of nucleotides also. So, this process is called transcription and finally, from RNA we will get the protein and this process is called so. Now if you see the information flow from nucleic acid to protein. So, from protein we are not making RNA or DNA. So, this is the central dogma that the information is always flowing from nucleic acid towards protein, but not in the reverse direction and this is true in all living entity and this is the central dogma.



I will discuss more in more detail in other classes and that is all. You can go through any of this textbook for additional details, that is all. Thank you.