Environmental Chemistry and Microbiology

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Module - 7
Lecture - 33
Overview of Microbial Life - I

Welcome everyone to lecture number 3 (lecture 33). We are going to start a new topic today, and that is an overview of microbial life. This topic has been divided into 3 parts. And we are going to look at different microbial groups.

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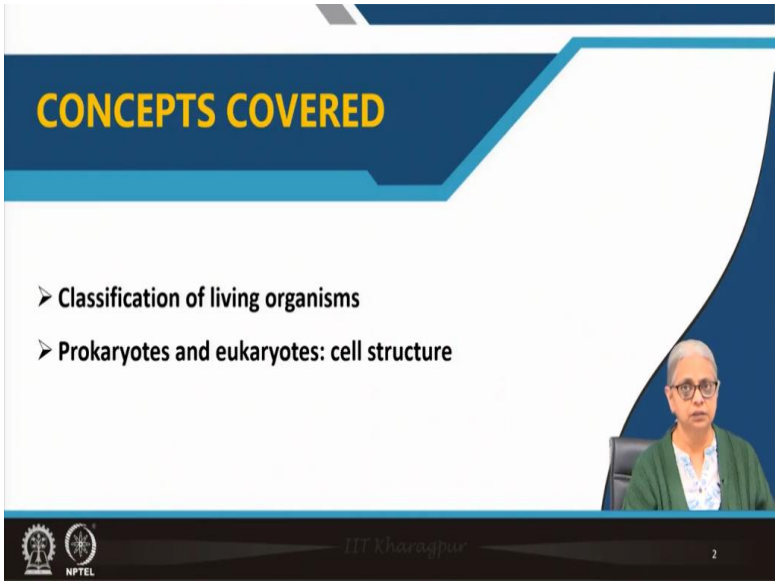

So, we are going to look at the classification of living organisms; we are going to look at the differences between prokaryotes and eukaryotes; those are the two main categories of living organisms; and their cell structure. We are also going to look at different microbial groups in subsequent parts. So, today in this particular segment, we are going to look at the classification of living organisms and prokaryotes and eukaryotes.

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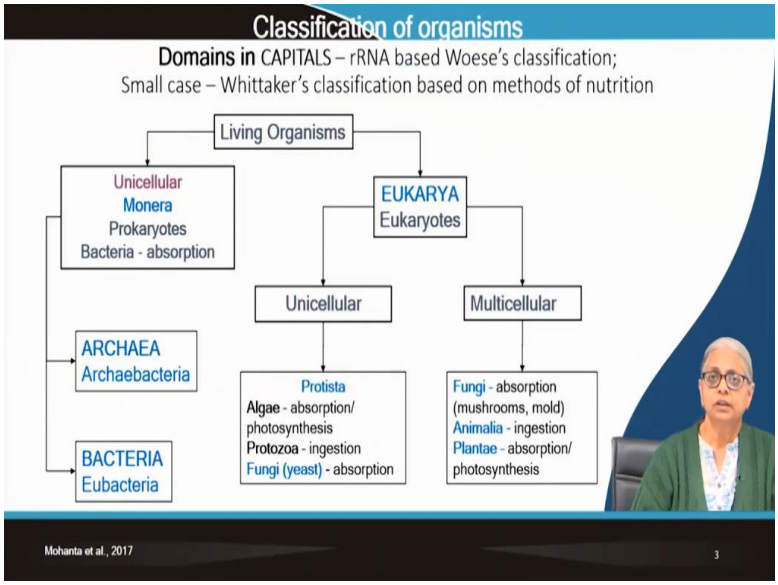

When we want to look at all living organisms, the first thing we need to understand is, how do we sort of classify them or categorize them? What is the basis of that categorization or classification? So, I am going to start with the classification of organisms. All living organisms, especially for those of you who had biology, some amount of biology in high school; you must have heard about prokaryotes and eukaryotes.

So, the fundamental difference, at the first level is, whether they are unicellular or multicellular. But then, when we talk about prokaryotes and eukaryotes, we do not really focus on the fact that all prokaryotes are unicellular by definition. But that is not the defining characteristic. The defining characteristic between prokaryotes and eukaryotes is that prokaryotes have no nucleus.

They have nuclear material, but they do not have a nucleus. So, they do not have a nuclear membrane. The DNA is a free-floating strand in the cytoplasm of the cell. And that defines your prokaryotes. Eukaryotes, on the other hand, have a well-defined nucleus. So, that is the defining characteristic that separates all prokaryotes from eukaryotes. And therefore, I have tried to mesh together two different methods of classifying all living organisms.

So, right at the top, we have two categories, prokaryotes and eukaryotes. All prokaryotes, by definition are unicellular. There are two very popular methods of classification. The current one; all current microbiology textbooks use the classification based on Woese's classification. It is based on ribosomal RNA. I will come to that later. This particular classification is the one that we studied when we were in school and that is Whittaker's classification, which is based

on methods of nutrition. So, just to make sure that we are very clear about the two ways of classifying all living organisms. It is very important, so that there is no conflict, no contradiction, etcetera. So, we are all aware of unicellular and multicellular organisms. All prokaryotes are unicellular, they are all bacteria. Within bacteria, we now have two domains based on Woese's classification, which I will talk about later. And those are archaebacteria and bacteria or eubacteria. These are the terms we use to use prior to Woese's classification. Within eukaryotes, you can have two groups. You have unicellular eukaryotes and multicellular eukaryotes. So, these unicellular eukaryotes are called protists. Protista is the name of the kingdom based on Whittaker's classification. They are call protista. They have algae and protozoa and they have fungi like; examples are yeast.

Then you have multicellular organisms which can have fungi. So, when you have your mushrooms next time, you know that you are dealing with a multicellular eukaryote. Mold can be both. So, there are different types of molds. And then you have plants and animals that we all see around us. So, this is the broad classification based on Whittaker's classification; and that is based on methods of nutrition.

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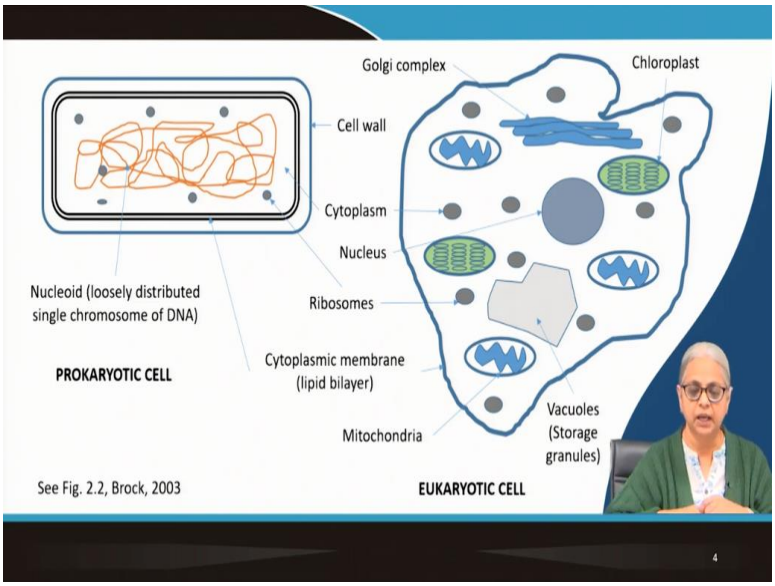

So, what you may have learnt in school is, what are the differences between prokaryotes and eukaryotes? So, you can refer to any textbook. All of them have these differences. They are very clearly mentioned. A prokaryotic cell is the simplest living structure or the simplest living organisms that are present on the planet are prokaryotes. They have extremely simple cell structures. They have a cell wall; and that is the outer layer. Within that, they have what is called a cytoplasmic membrane or a plasma membrane. And that keeps all the cytoplasm inside

the membrane. As I said, they have a loosely floating DNA strand. So, for bacteria, there is a single circular chromosome. It is a double strand of DNA, which forms a single chromosome. So, it is a long circle. You can think of it as a thread; and a thread that has two strands in it; and it is a circle; unlike all the other higher organisms which have linear chromosomes. So, this is a prokaryotic cell which has a single chromosome, which is a double stranded DNA molecule. It is a single molecule and it is a long, long circular molecule. This is a nucleoid, because there is no nuclear membrane that separates the DNA from the rest of the cell.

So, here we have the cytoplasm. Everything inside the plasma membrane is the cytoplasm. You have ribosomes in it. These are the small grey structures and this is the site of protein synthesis. And you have the DNA. The DNA is not compactly folded. It is free floating inside the cytoplasm. And there is no well-defined nucleus. So, these are the simple characteristics of a prokaryotic cell.

Look at the eukaryotic cell, on the other hand. It may or may not have a cell wall. For example, plant cells have a cell wall; animal cells may or may not have a cell wall. They are all defined by a well-defined nucleus. So, this nucleus is where the DNA of the eukaryotes is placed. So, this is all very compactly folded; and it is all in closed by the nuclear membrane. This is the cytoplasm. There are several other organelles that are present in the eukaryotic cell. So, you have mitochondria. If it is a plant cell or a photosynthetic organism, it will have chloroplasts, as you can see over here. Golgi complex; ribosomes are present in both. The cytoplasmic membrane is also present in both. Eukaryotic cells have another interesting feature and that is vacuoles or storage granules. So, when environmental conditions change very often, you can have feast, you can have famine. So, when there is enormous amount of food in the environment, these, especially the microbial organisms, they have the ability, even bacteria have the same ability, yes; they have this ability to store whatever is required.
And then when the environment becomes less favourable or becomes hostile and the food is depleted, they are able to use whatever is stored within their bodies; and they can survive even under those hostile conditions.

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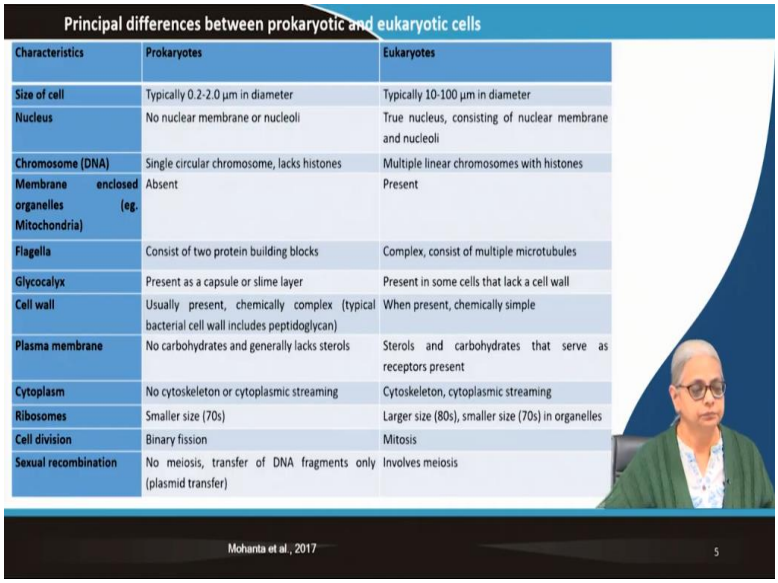

So, here are all the differences between prokaryotes and eukaryotes. One of the biggest differences; like I said, the defining characteristic is whether the nucleus is existing or not. If there is a nucleus, it is a eukaryote; if there is no nucleus, it is a prokaryote. Then we have size of the cell. So, if you have small; most of the prokaryotes are very small sizes. It ranges from 0.2 to 2 microns in diameter.

For eukaryotes, it can go from 10 to 100 microns or even higher. Chromosomes: I have already mentioned that the prokaryote, the bacteria, have a single circular chromosome; there are no histones. And the histones are used for organising these chromosomes. So, you have multiple linear chromosomes with histones in eukaryotes, not in prokaryotes. Organelles within the cell, are they membrane enclosed?

So, in eukaryotes which are higher in terms of complexity, there are membrane enclosed organelles; and in prokaryotes, none of them are enclosed in a membrane. For movement, you have flagella. So, these unicellular organisms, if you are dealing with unicellular organisms, they have flagella; flagella used for movement. In prokaryotes, you have flagella which have two protein building blocks; and in eukaryotes, you have complex flagella with multiple microtubules.

So, they are more complex structures. There is a glycocalyx. It is present as a capsule or a slime layer. And in eukaryotes, it may be present in cells that lack a cell wall. Like I said, a cell wall is another defining characteristic of prokaryotes. It is almost always present, because, remember, these cells are independent living organisms. So, without a cell wall, they cannot

survive in their environment. They need a wall. And so, it is almost always present. I do not know if any exceptions. And a typical bacterial cell wall contains what is called peptidoglycan. And this is a very important component of the cell wall, which I will describe in subsequent topics. It is a chemically complex structure, so we will be going through it later. And then in eukaryotes, if there is a cell wall; I have already mentioned that plant cells always have a cell wall, animal cells may or may not have a cell wall; and when they have a cell wall, it is generally chemically simple.

This also determines how it reacts with certain chemicals and antibiotics and so on. So, this cell wall and how it reacts to the presence of different compounds, is another very important point from the medical perspective. And we are not going to go into that direction, but it is important to remember that.

Then we come to plasma membrane. Plasma membrane is again present in both. In prokaryotes, there are no carbohydrates and it generally lacks sterols. Sterols and carbohydrates serve as receptors in eukaryotic plasma membranes. The cytoplasm is also present in both. However, in prokaryotic bacteria, because the cell wall is somewhat rigid, there is no cytoskeleton and no cytoplasmic streaming. So, if you are familiar with amoeba and you have heard of the fact that amoeba will stream towards- the entire cytoplasm will flow in one direction towards a food particle that the amoeba wants to ingest. So, when it is moving in one direction, it forms what is called a false foot. And that is also, that process is also called cytoplasmic streaming. So, this cytoskeleton and cytoplasmic streaming is a phenomenon that has been observed only in eukaryotic cells. It has never been observed in prokaryotic cells, because, perhaps because of the rigidity of the cell wall.
Then we come to ribosomes. The ribosomes in prokaryotes have a smaller size. And 70s and 80s is based on what is called the sedimentation rate. So, the smaller size of the ribosomes is another defining characteristic. And eukaryotic cells have larger sizes; they are 80s. Cell division in prokaryotes is strictly binary fission. So, there is no sexual reproduction, in general. By and large, most of the time; there are very few exceptions; you have binary fission as the method of reproduction.

In eukaryotic cells, you can have both. You can have binary fission, you can have asexual reproduction as well as sexual reproduction. Where there is sexual reproduction, there are two processes mitosis and meiosis. Sexual reproduction requires the combination of two haploid

cells. And when those 2 haploid cells are conjugated, you get sexual recombination, which can never happen in prokaryotes.

So, by and large, because there is no sexual reproduction, you do not get sexual recombination. There is no change in the DNA code because of that. And therefore, this does not happen. However, the only exceptions that we do know about are the fact that there are certain plasmids. These plasmids can be transferred from one bacterial cell to another. That can result in sexual recombination, which means, the DNA code of a particular bacterial cell can be altered. But it is not the same as the eukaryotic cell. So, the nature of sexual recombination in prokaryotes is very different. So, the transfer of DNA fragments by plasmid transfer is possible. One of the reasons for saying a lot about this is antibiotic resistance of certain bacteria. So, very often, when we get bacterial infections, we go to the doctor and they prescribe antibiotics. And then, after some time, it has no impact. Then, you go back to the doctor and say, what is the problem? And that is because the bacteria that has caused the infection has modified itself to become insensitive to the antibiotic that you are taking. So, it has become resistant. It is no longer; the infection is not being cured by the antibiotic that has been prescribed. So, this antibiotic resistance has become a major phenomenon in healthcare; and that is because of this phenomenon.

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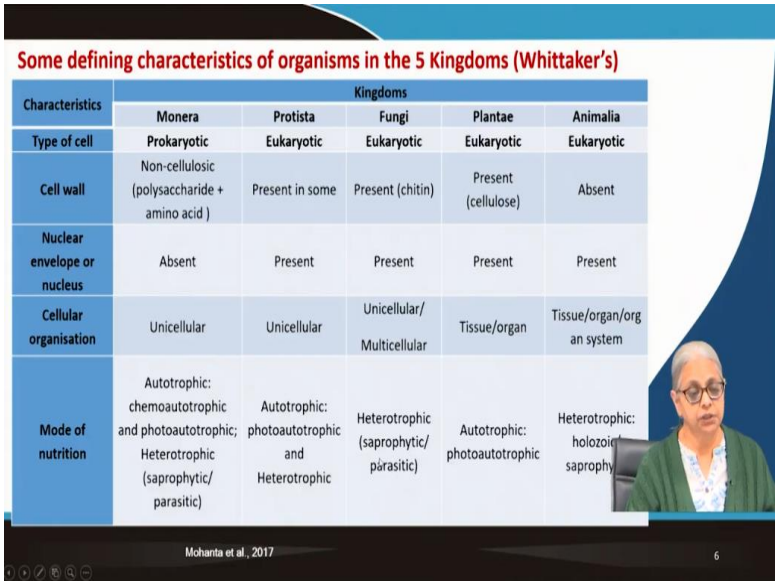

Characteristics	Kingdoms				
	Monera	Protista	Fungi	Plantae	Animalia
Type of cell	Prokaryotic	Eukaryotic	Eukaryotic	Eukaryotic	Eukaryotic
Cell wall	Non-cellulosic (polysaccharide + amino acid)	Present in some	Present (chitin)	Present (cellulose)	Absent
Nuclear envelope or nucleus	Absent	Present	Present	Present	Present
Cellular organisation	Unicellular	Unicellular	Unicellular/ Multicellular	Tissue/organ	Tissue/organ/organ system
Mode of nutrition	Autotrophic: chemoautotrophic and photoautotrophic; Heterotrophic (saprophytic/ parasitic)	Autotrophic: photoautotrophic and Heterotrophic	Heterotrophic (saprophytic/ parasitic)	Autotrophic: photoautotrophic	Heterotrophic: holozoic/ saprophy

So, let us take a quick look at Whittaker's classification also. Whitaker's classification, which is what we learnt in school; so, that is why I am reiterating it here. That is, like I said, based on methods of nutrition and certain characteristics of the organism. So, these are 5 kingdoms.

Monera, for all prokaryotes; protista; fungi; plantae; animalia. So, within eukaryotes, you have 4 kingdoms; and within prokaryotes, you have just one.

So, these are differences based on cell walls. Bacterial cells which are prokaryotes, they are non-cellulosic, polysaccharides plus amino acids. Cell walls may be present in some protists; most of them have a cell wall. Fungi always have a cell wall and it is made of chitin. Plants always have a cell wall. It is a rigid cell wall made of cellulose. Animals do not in general have a cell wall, i.e., animal cells.

Then, you have a nucleus or a nuclear envelope which is absent in prokaryotes and it is present in all eukaryotes. That is the defining difference between prokaryotes and eukaryotes. In terms of cellular organization, prokaryotes are always unicellular. Protists are also always unicellular. Fungi are unicellular or multicellular. So, if you have yeast cells, if you have mold; some molds are unicellular, some are multicellular. And mushrooms are examples of multicellular fungi. Plant are tissues; and plants will have tissue and organs; and so will animals. So, these are higher organisms, which we are not going to be dealing with, but it is important to remember that they exist.

Then we have a mode of nutrition. How do they get their mass as well as energy? What is the mode of nutrition? How do they get their nutrients? You can have both autotrophic and heterotrophic. And if you have forgotten, we will be covering that in a little bit. Autotrophic is self-feeding. They do not feed on other living organisms. They generate their own biomass and their own energy. And then, you have heterotrophic organisms which feed on other living organisms; or living or dead organisms. So, they depend on others for their food.

Now, within prokaryotes, within bacteria, you have both types. Similarly, protista which include protozoa and algae, they can be autotrophic. So, you know that algae are autotrophic and protozoa are heterotrophic. Fungi are heterotrophic. They feed on dead biomass. So, you know, when you have seen mushrooms and mold growing on all kinds of surfaces, they are saprophytic microorganisms. So, these saprophytic microorganisms; we also call them decomposers; they feed on dead biomass.

You can also have parasitic microorganisms or even higher organisms. So, you can have all kinds, multicellular as well as unicellular. Plants, by definition are autotrophic. They are

photosynthetic organisms. So, they do not feed on other living organisms. They are the ones that convert CO_2 to biomass.

Then we come to animals. Animals, by definition are heterotrophic. They feed on other living organisms. They can be holozoic, in the sense that they ingest other organisms, either completely; they completely ingest something. So, when I showed you the video of a paramecium eating bacteria, that is actually a protist, but that is also holozoic. So, it is eating or ingesting the entire organism.

And then, you can also have saprophytic animals; scavengers. And you can call them scavengers, you can call them decomposers, but these are the organisms that are converting dead biomass and recycling the nutrients back into the nutrient pool. So, the biogeochemical cycles depend on many of these organisms.

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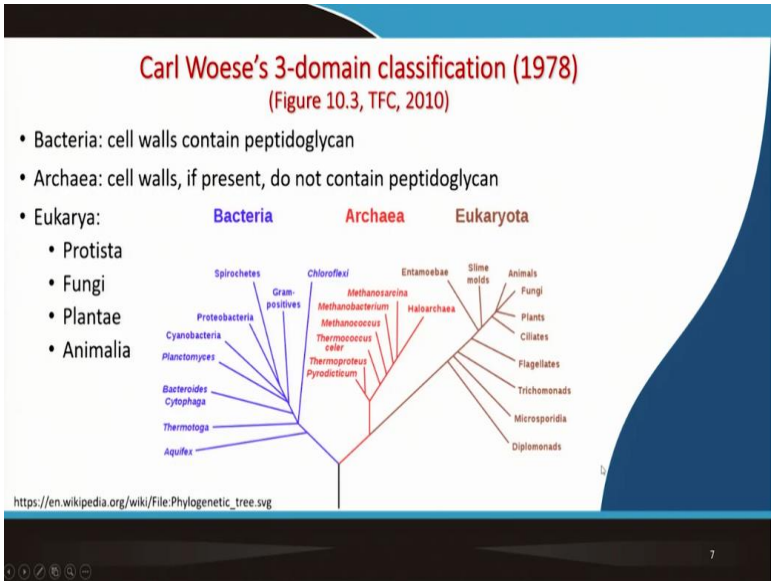

As I mentioned earlier, we are going to look at the current method of classifying organisms. This method of classifying organisms is relatively new. It is as old as 1978. So, Carl Woese came up with a 3 domain classification. Now, these domains are higher than the kingdoms. So, again, back to these kingdoms; and then you have the domains that are higher than that.

So, he has defined 3 domains: Bacteria, Archaea, and Eukarya. So, Bacteria and Archaea are both prokaryotes, while the Eukarya by definition are eukaryotes. So, based on ribosomal RNA sequencing, they have come up with this tree of life, if you want to call it; yeah, that is exactly what it is.

The phylogenetic tree or the tree of life, where you have the last universal common ancestor at this point and at this point, based on the ribosomal RNA sequencing, there are 3 major branches. So, these are the 3 domains: Bacteria, Archaea and Eukarya. So, like I said, there are 3 domains: Bacteria, Archaea, and Eukarya. Bacteria and Archaea are both prokaryotes. And the difference between Bacteria and Archaea is the fact that, peptidoglycan is present in Eubacteria or Bacteria; while Archaeabacteria, they do have cell walls, but they do not have peptidoglycan.

Now, these Archaebacteria are generally not found in the normal environment that we are looking at; I mean, you can look around you and that is what I call a normal environment. Those are the bacteria that exist in your normal environment are basically Eubacteria. These Archaebacteria are not going to be found in your normal environment. They are generally extremophiles and you can see some examples over here. Haloarchaea are the ones that survive in saline environments. They are used to high levels of chloride or salinity. You have these methanogenic bacteria. They are capable of generating methane. And for those of you who know about wastewater treatment, you know that biogas is generated in anaerobic digesters by methanogenic bacteria along with other bacterial species.

So, these are strictly anaerobic bacteria. They cannot survive in the presence of oxygen. So, you are not going to find them around you where oxygen is plenty. So, these are extremophilic bacteria that prefer very well-defined environments. And those are not similar to what we have around us. Then we have eukaryotes. So, you have all kinds of eukaryotes. You have flagellates, ciliates, plants, fungi, animals, and so on. So, this is a very simplified diagram, but it gets quite complex. We are not going to go too far with it.

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So, here are some SEM as well as TEM images of different types of bacteria. So, you have *E. coli* bacterium, which is a eubacteria or a bacteria. So, this is a TEM. And this ripple like structure beyond the cell wall is what is called the lipopolysaccharide layer. This lipopolysaccharide layer is what gives the slimy touch to many of these; so, that is the one that causes the biofilm to form and it will stick to surfaces and that is what allows these bacteria to stick to various surfaces. So, then we have archaebacteria. This is a eubacteria. "Eu" meaning good, but it really means modern. They are more modern. Archaebacteria; perhaps I am not 100% certain about this, but archaebacteria perhaps give us an idea about how life began, way back when there was no oxygen on the planet and life obviously began under those conditions. Those were extremely harsh conditions compared to what we see now. So, these archaebacteria, perhaps more primitive compared to the eubacteria; and they give us some idea of those conditions under which life began. So, here you have some archaebacteria. We have *Methanococcus janaschii*. It is a coccus form with numerous flagella. You can see the flagella distributed around the outside of the cell.

And then you have *Methanosarcina barkeri*, which is a lobed coccus which lacks flagella. You have a short bacillus type bacterium, which has no flagella. And another one which has an elongated form. So, these are all examples of archaeal species.

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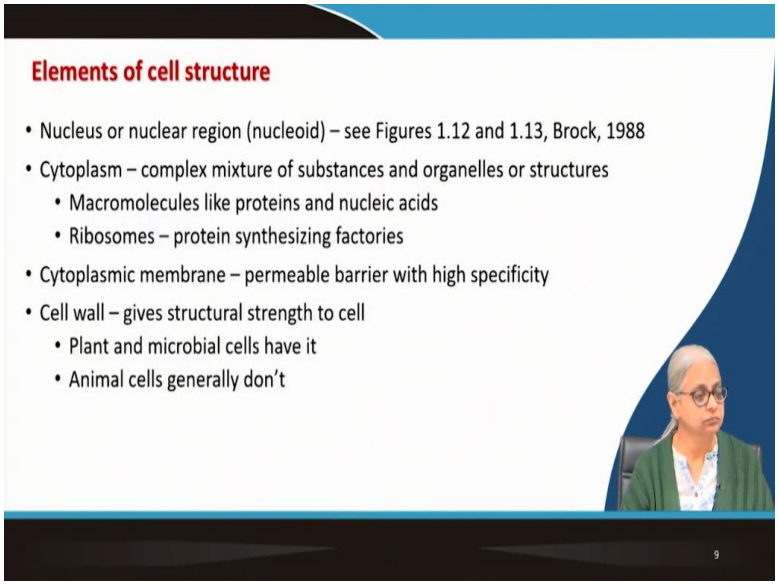
In terms of cell structure, what do we have? Like I said, one of the major defining characteristics between prokaryotes and eukaryotes is the nucleus or the nuclear region. You can refer to any of the textbooks for lots of different SEM and TEM images of the nucleus or

the nuclear region. And let me point out something right here. So, this white space that you see, that is the nuclear region in the *E. coli* bacteria. This white space, these are all nuclear regions. It is not enclosed in a nucleus. So, that is why you can see it freely distributed throughout the cytoplasm.



What is the cytoplasm? It is a complex mixture of substances with organelles as well as structures. You have macromolecules or biopolymers, like proteins and nucleic acids. You have ribosomes, which are the sites of protein synthesis. It has to be contained in a cytoplasmic membrane. This cytoplasmic membrane is highly permeable. They will not allow any and every compound to pass in and out. There is a very high degree of specificity. And we will be looking at this quite closely in subsequent topics. So, this permeable barrier, even though it is permeable, it has a very high degree of specificity, even to the extent that water cannot pass in and out without some proteins mediating that transport.

Then we come to cell walls. Cell walls are required for giving structural strength as well as what we call integrity to the cell, because it cannot exist independently unless there is a wall around it. So, microbial cells as well as plant cells have cell walls, while animal cells generally do not have cell walls, for the simple reason that they are differentiated into tissues and organs and they do not need a cell wall.

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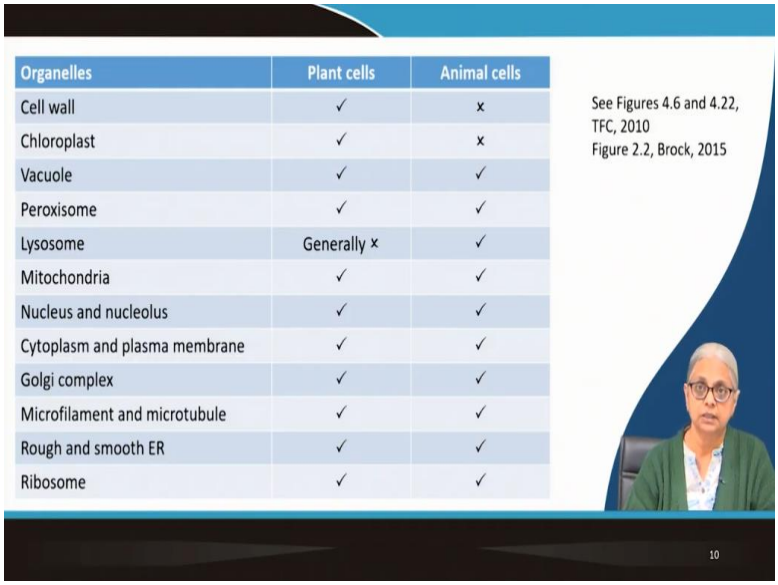

So, just to summarize, some of the differences between plant and animal cells. Cell walls and chloroplasts are present in plant cells, but not in animal cells. All the other organelles including lysosomes, vacuoles, peroxisomes; lysosomes which contain the enzyme lysozyme; mitochondria, which is the site of ATP synthesis; the nucleus which contains the DNA; the plasma membrane and the cytoplasm which contains everything else; Golgi complex; microfilaments; microtubules; rough and smooth endoplasmic reticulum; and the ribosomes; all of them are generally present in both plant as well as animal cells. There are good graphics in the textbooks that I have recommended here. So, you can refer to any of them at any point.

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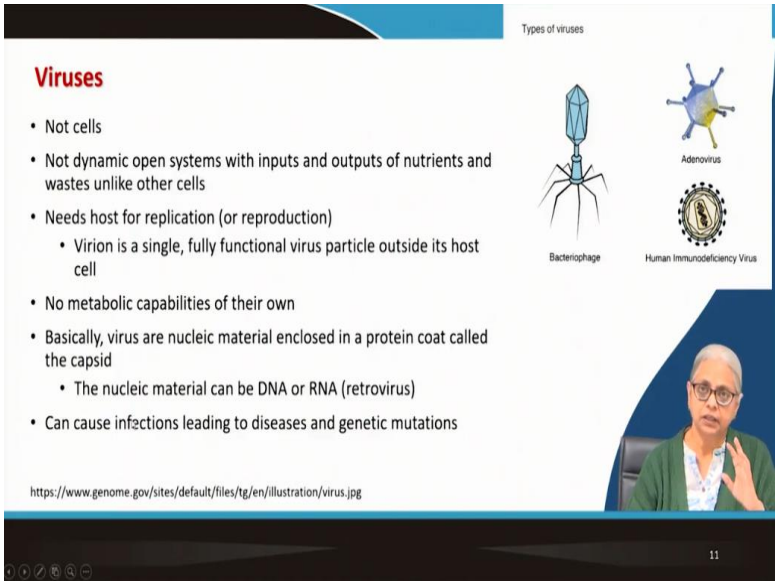

Coming to the last but not the least, we come to viruses. Are viruses living organisms? As long as they are outside the host, they are non-living, because they have no ability to reproduce or grow without a host. They need a host to grow and reproduce. So, they are not cells. They are

not considered living organisms as long as they are outside the host. They are not dynamic open systems. If you remember, in the previous lecture I said, is any cell an open system? Is it a dynamic open system? And the answer for viruses is, they are not. They are neither dynamic nor open. Because, while they are outside the host, they are enclosed in a coat or a capsid. So, this capsid or coat is static; it does not allow the virus (to replicate). What is inside that coat? In general, it is a DNA molecule, but in some cases like the Coronavirus or the HIV virus, you can have an RNA molecule rather than DNA molecule. So, there are possible exceptions, but in general its DNA. And if it is an RNA, it is a retrovirus. They cannot reproduce, like I said, without a host. So, all replication and reproduction happen after the (viral) DNA or the RNA is injected into the host cell.

The host ATP and other functions are taken over by the viral DNA and that is how the infection happens. So, it has no metabolic capabilities of its own. It depends on the host for all its metabolic capabilities. And it is nothing but nucleic material enclosed in a protein coat, which we call the capsid. So, you can see examples of all of that here. A bacteriophage is a virus that infects bacterial cells. These are two examples of human viruses. Adenoviruses cause colds. And your normal common cold is caused by adenovirus. HIV, which causes AIDS; it is an auto immune deficiency syndrome that is caused by the HIV virus and that causes infections in human beings. So, these infections can lead to diseases; it can lead to genetic mutations; it can lead to cancers; all these things have been proven by now.

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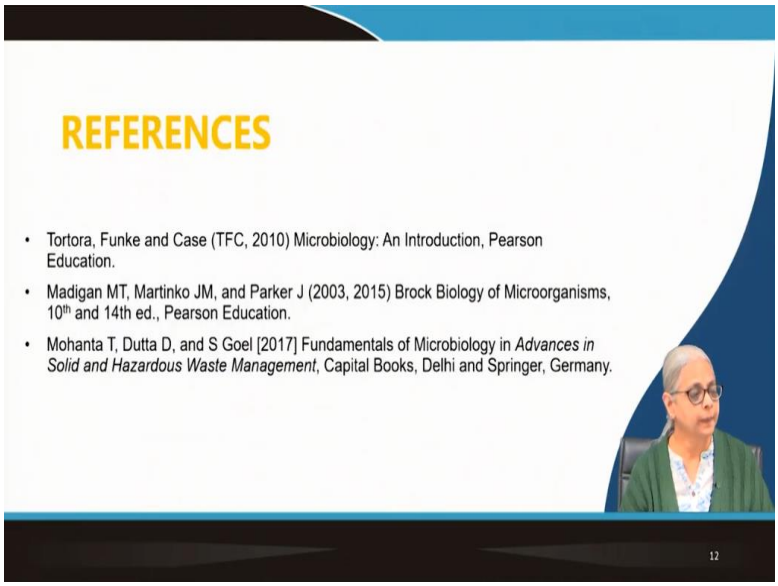

I will end it in this part here. Thank you.