Environmental Chemistry and Microbiology
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Module - 7
Lecture - 31
Introduction - I

Welcome, everyone to our NPTEL course, an online course on Environmental Chemistry and Microbiology. This course is going to be taught by Professor Anjali Pal and myself, Sudha Goel. We are both from the Civil Engineering Department of IIT Kharagpur, and Professor Anjali Pal will be teaching about Environmental Chemistry, while I will be covering Environmental Microbiology.

We have divided this course into two parts, like I said, Environmental Chemistry and Environmental Microbiology. I will start with the Environmental Microbiology part today. So, our first module is going to be an Introduction to Environmental Microbiology.

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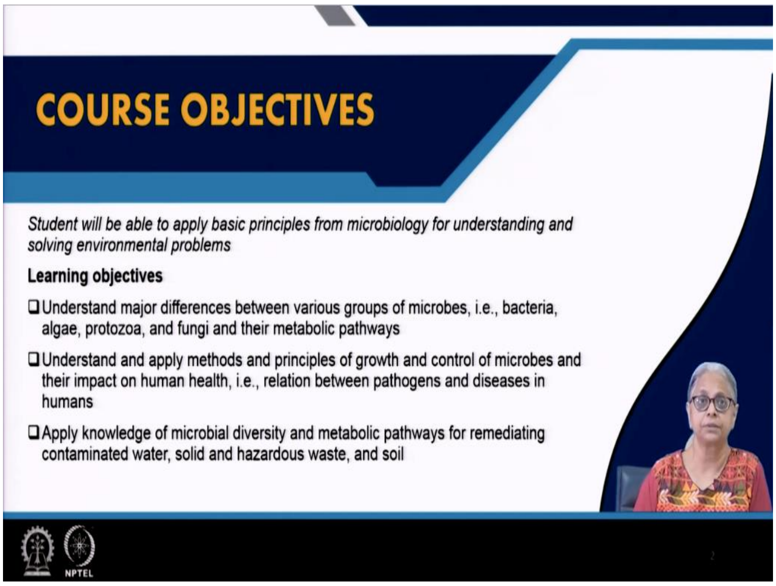

Now, within this particular half, within this second part of the course, what is our objective? Our objective is that every student who has taken this course, should be able to apply the basic principles from microbiology for understanding and solving environmental problems. So, the first thing you will learn is to recognize the different groups of microorganisms and these include bacteria, algae, protozoa, and fungi.

We will look at their metabolic pathways. When I talk about metabolic pathways, what we are looking at is - how do these organisms obtain food that they need for generating new biomass as well as energy for their survival. Remember that from a biological perspective, all organisms have basically two objectives - one is to survive in their environment and the second is to reproduce.

So, for that, their metabolic pathways will determine how they survive and how they reproduce. So, we will be covering that in the first part of the course. In the second part of the course, we want to look at the different methods for culturing these microorganisms and for controlling their growth. Most of you are well aware of the fact that microorganisms are often associated with severe diseases in humans and other organisms as well.

So, we want to apply these concepts of growth and control of microorganisms and their impact on human health. So, we will look at the relationship between certain pathogenic organisms and diseases; that is pathogenic microorganisms. Finally, and from an environmental perspective, we need to understand microbial diversity. This part of the biosphere is one of the most diverse parts of the biosphere and the metabolic pathways that these microorganisms are capable of utilizing are extremely diverse. We will go through all this.

The main intent of going through these diverse metabolic pathways is for you to be able to apply them for remediating, for solving the contamination of water, solid waste, hazardous waste, soil pollution. All these things can be tackled based on our understanding of microbial principles.

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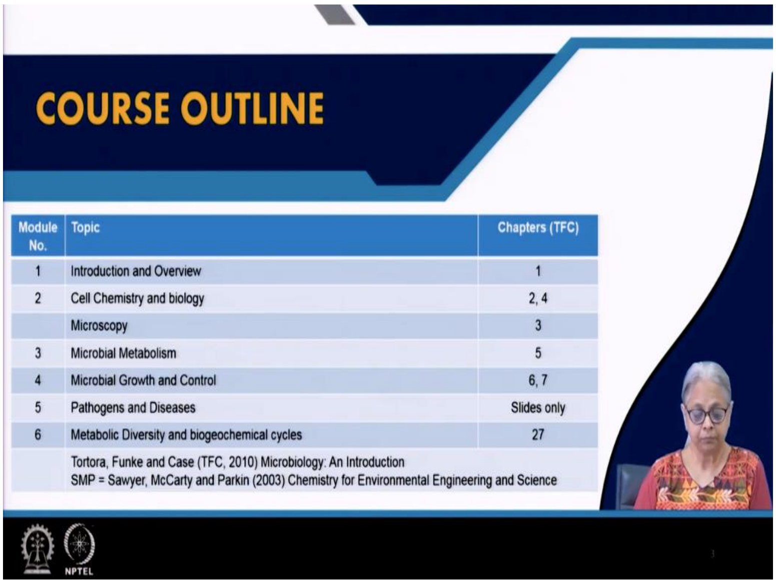

So, this is an outline of some of the topics that we will be covering. I am using 3 textbooks. They are referenced in the final slide. The main textbook for this course is by Tortora, Funke and Case; and the title is Microbiology: An Introduction. So, the main chapters are from there.

So, we will start like I said today with the introduction and an overview of microbial life. Then we will come to cell chemistry and biology followed by microscopy.

Remember that our ability to visualize cells is crucial to our understanding of these microorganisms because they are not visible to the human eye. Metabolic pathways and how these microorganisms are able to survive as well as reproduce; comes under the third topic, microbial metabolism. Then we go to microbial growth and control, followed by pathogens and some of the diseases related to these microbial pathogens; and finally, to metabolic diversity and the biogeochemical cycles.

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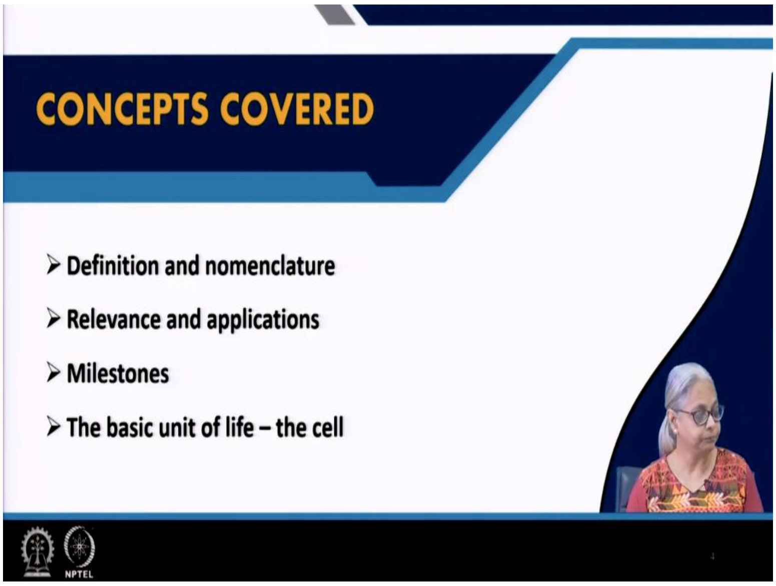

So, for today's lecture, we are going to go through some basic fundamentals, which you may have studied in your high school or even your bachelor's degree programs. But just to make sure that we are all on the same page, let us go through the definition of microbiology and the nomenclature that is used in naming the species. Then we will go through their relevance, the relevance of microbiological principles, and some applications.

Some major milestones in the history of this discipline: This discipline has matured in the last almost 400 years. And we will go through some of the basics of microbiology or you might say biology itself. The basic unit of life is the cell. So, we will go through a very quick review of that.

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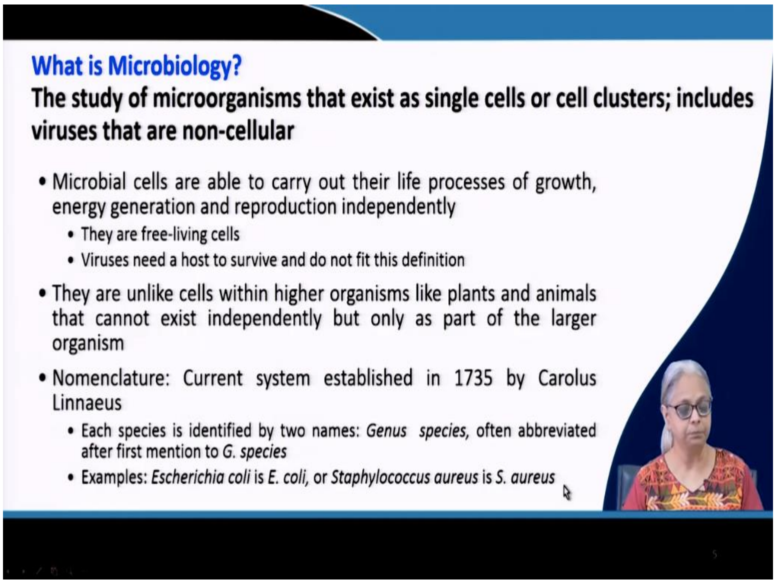

So, coming to what is microbiology. Microbiology is the study of microorganisms. And these microorganisms are capable of existing as single independent cells or they might form cell clusters. These cell clusters allow these microorganisms to live independently, even though they are kind of stuck together, but they remain independent. And if you think about yourself and compare yourself to a microorganism; it sounds bad, but bear with me about that. If you take a single cell from your body, it is not going to be capable of living independently. So, even though our bodies are made out of cells; and if you extract a single cell from any human being or even any of the other higher organisms, none of them is capable of living independently. Unlike higher organisms, microbial cells are capable of carrying out their life processes. Life processes involve growth, energy generation, and reproduction; and they are capable of doing this without depending on any other cells, even within their own community or within their own species. So, these are free-living cells.

When we talk about microorganisms; we are living right now in the COVID-19 period and we are worried about Coronavirus. These viruses are also part of microbiology, even though they do not fit the classical definition of a microbial cell; because viruses, unlike other microorganisms, need a host to survive. They are incapable of surviving on their own, they do not fit the definition of microbial cells, but because of their size, we normally include them in microbiology.

And these microbial cells, as I said, are unlike cells of higher organisms; whether it is plants, animals, human beings, it does not matter; they can; the higher organism cells cannot exist independently; only as part of the larger organism.

Then we come to the nomenclature. This particular nomenclature was established as far back as 1735 by Carolus Linnaeus, and it is based on two basic names. Just like my first name and my last name, so you have a genus and a species. So, the first name is the genus and the second name is the species; and often we write it in this particular form. So, if you look at this, this is the genus, this is the species.

So, we abbreviate the name after the first full mention, which we abbreviated to genus dot species. So, Escherichia coli, which is a common inhabitant of our gastrointestinal tract is going to be shortened and written as E. coli and Staphylococcus aureus, which is again a very common pathogen in our environment is shortened to S. aureus. So, this is the simplest way of naming and identifying different species of microorganisms or even higher organisms.

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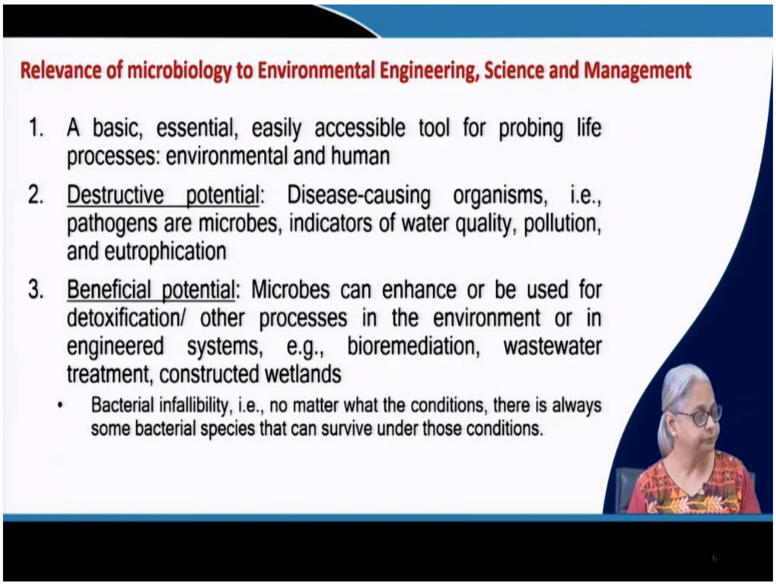

What is the relevance of microbiology to environmental engineering, science, and management? The first thing that I still remember being taught even as a student was that microbiology offers a basic essential tool for us to probe life processes. I started by saying you can imagine yourself and with comparison and contrast with bacteria. You can understand how many things that we are doing are similar to the bacteria.

We need to grow; we need to survive; we need to reproduce; all these are parts of our biological requirements. So, our understanding of bacteria and how the bacterial cell or even the microbial cell works; especially when we think about metabolic pathways, is very essential to our understanding of how human beings obtain their food, how they obtain energy, and so on. There are so many similarities between the different organisms.

And then we also use bacteria as well as other microorganisms to understand environmental processes. So, what is happening in the environment can be understood based on how microorganisms behave in the environment. Remember, everything is tied. The abiotic part, the one that does not have life is intimately related to the biotic part. So, what the biotic part does is, modify the abiotic part; it uses the abiotic part of the environment to get its nutrients. And in that process, the organisms including microorganisms are modifying the environment. So, it is an intimate relationship between the abiotic and the biotic parts of the environment. And our understanding of what happens in the environment is absolutely based on our understanding of microbiology; you cannot separate the two, and I will come to more examples of that.

The second one, for some, maybe extremely important. We are going to look at this aspect as well, but we are not going to spend too much time on it. The first thing that comes to most people's mind when I say bacteria or virus; they will think about, oh! I had a bacterial infection, oh! I had a fungal infection, I had a viral infection, etcetera, right. So, these microorganisms are often associated with the disease. These disease-causing organisms are called pathogens. These pathogens can be microbes or higher organisms like worms and all, which we will not get into, but we will focus on microbial pathogens.

We also use microbial species, especially bacterial species like E. coli, as indicators of water quality. So, for those of you who come from a water quality background or civil engineering, environmental engineering; those of you who have studied any of these disciplines, you must be knowing that we are required to monitor coliforms in water. And that is an indicator of water quality. Because, if I have total coliforms, there is a suspicion that there is possible fecal contamination. And then if I further monitor or examine the water quality for fecal coliforms and I find it positive for fecal coliforms, then I am absolutely certain that, that water is contaminated by wastewater. So, this is a very important indicator of water quality.

We also use it (microbes) as an indicator of pollution; we use it as an indicator for eutrophication. The simplest example of eutrophication is: you walk around anywhere in the cities, towns, countryside, wherever you go, you will find small puddles of water or even large water bodies which have a green layer at the top. That green layer comes from algal cells. These algal cells are also microbial organisms and they bring the water quality down.

So, why do they grow? They grow because there are excessive nutrients in the water. And that leads to eutrophication and lowers water quality. So, we will be spending some time on some of these destructive aspects of microbial organisms.

Third: It is very important. Once you understand that, yes, there are certain species of microorganisms that are a problem that causes diseases, they lower water quality, even air quality, we are living through those times; they are not all bad. In fact, the majority of microorganisms are not bad. They have a beneficial impact. They have a beneficial potential, both within our bodies as well as in the external or commercial world. So, we will look at some of those applications. Even our ability to digest complex food is dependent on the microbial flora of our gastrointestinal tract.

So, we cannot really survive without these microorganisms. So, these microorganisms can enhance or be used for detoxification of environmental media. When I say environmental media, I mean in the natural environment; or you can design engineered systems. So, if you are designing engineered systems like wastewater treatment processes, water treatment processes like disinfection, you might want to bioremediate certain areas; I will give you examples of all of that.

We will look at like I said, wastewater treatment; we have activated sludge process; we have trickling filters; we have so many other types of biological processes, which I do not know if we will have time for that, but I will definitely go through some examples. And then we have areas or natural engineered systems like constructed wetlands, which are again a symbiotic relationship between microorganisms and plants.

So, all these are examples of the beneficial or useful potential of microorganisms. I have a somewhat humorous point over here at the bottom and that is called bacterial infallibility. Bacterial infallibility from, as the name suggests is, the bacteria can never be wrong. But that is not what we want to say here. What we want to say here is that no matter what the environmental conditions are on this planet; you go to any part of this planet, it can be the coldest part, it can be the hottest part, it can be the deepest part of the ocean, it can be the highest part of the planet; it does not matter where you are, you will always find some bacterial species that have been able to survive under those harsh conditions.

And our ability; coming back to the first point; our ability to understand how life evolved on this planet and how it has modified the environment to allow oxygen using organisms like human beings and so many other organisms that now live is based on the ability of microbial organisms to survive under extreme conditions. Remember, life began when the earth was a sort of teeming cauldron. It was extremely high temperature, high pressure, all those conditions under which today we cannot imagine life being possible. But those are the conditions under which life began. And slowly, the entire environment of the planet has been modified and allowed different species to emerge. So, these extreme environments, these harsh environments where we think, oh! it is impossible for anything to survive over here, some bacterial species are surviving and modifying those harsh environments.

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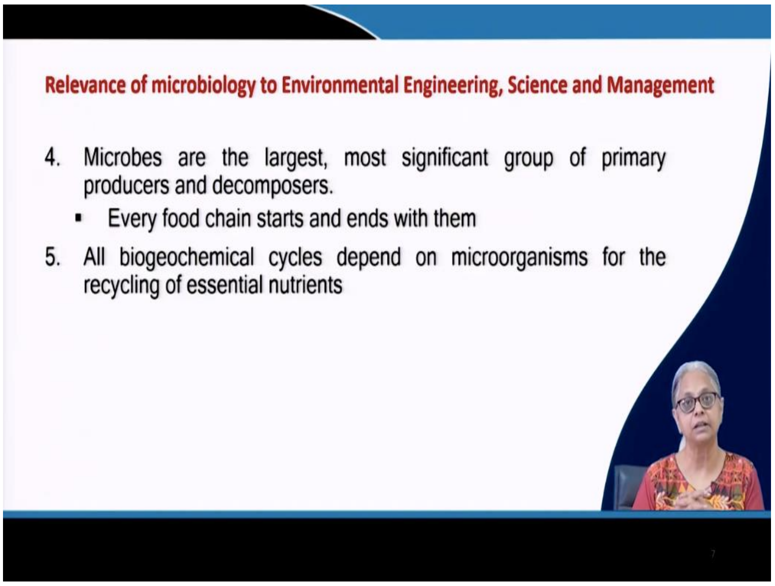

Let us come to another one. And those of you who know a little bit of ecology must be knowing about the food chain. We know that amongst the primary producers, we have the plants, but there is also another huge group of microorganisms and that is the algae. These algal cells have been one of the largest and most significant groups of primary producers. And then we have bacteria, fungi and so many other microorganisms that are decomposers.

And some of the bacteria; without forgetting to mention that; some of the bacteria are primary producers as well. So, they are autotrophic organisms. So, these autotrophic organisms are essential for the beginning of the food chain and after the end of life for all organisms, which happens. In the end, the decomposers are also microorganisms. So, life begins and ends with these microorganisms.

The last one, not the least, is biogeochemical cycles. Our ability as well as the microorganism's ability to survive in the environment is based on recycling, the natural recycling of essential nutrients. Without these essential nutrients being recycled by nature; and we normally use the word by nature; it is actually work done by microorganisms. It is the microorganisms that are doing all this work of recycling essential nutrients.

Because, if this recycling were to stop, what will happen is that there will be no nutrient availability for subsequent generations to survive. So, nature has been recycling these essential nutrients and depending on microorganisms for doing this job.

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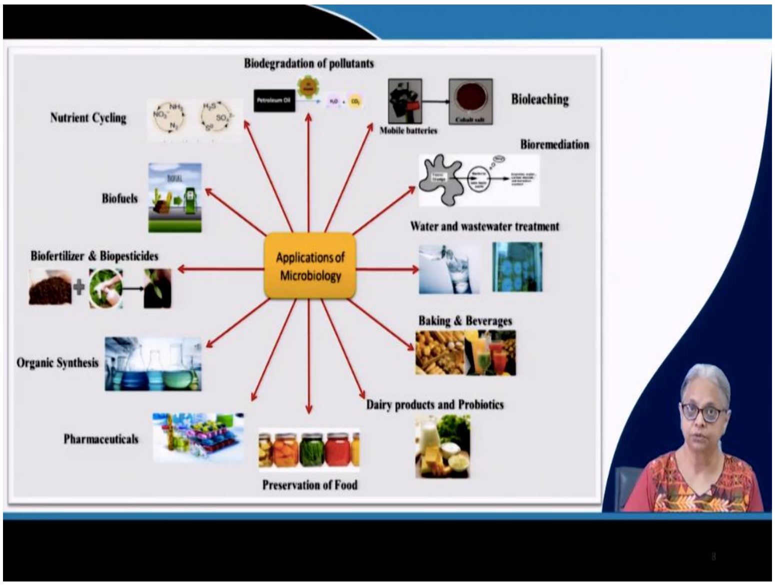

I will very quickly go through certain applications. The number of applications of microbiology that are relevant to today's world is almost infinite, but I will go through some of them. So, I will start with Nature. So, here right at the top, we have nutrient cycling. As I said, the biogeochemical cycles are absolutely essential for life to continue on the planet. And without the recycling; I have shown you examples over here of nitrogen and sulfur; but we normally focus on the big 6, so we have carbon, hydrogen, oxygen, nitrogen, sulfur, and phosphorus.

So, these are the big 6 macronutrients. And we have biogeochemical cycles for keeping them going within the environment. And that is a natural phenomenon that is mediated by microorganisms. So, we will go into some of these details within the course. Let us look at some of the anthropogenic; I think the rest of all the applications over here are anthropogenic. We live in an age when we want to minimize greenhouse gas emissions; we want to minimize waste in the environment, which means we should be able to convert waste into useful products. So, the first thing that we are doing these days is, we have water and wastewater treatment. Under wastewater treatment, we can convert part of the sludge that comes out of the wastewater treatment process, which can be converted to biogas. You can also use algal cells. I will show you an example in a minute. You can use algal cells to convert biomass into biodiesel or biofuel.

You can create compost, biofertilizer, biopesticides. Many of the plants secrete or create certain chemical compounds which have natural pesticidal properties. So, all these are possible. Several organic compounds can be and have been synthesized in the lab using microorganisms. Antibiotics, one of the biggest groups of pharmaceutical drugs and so on are manufactured by microorganisms.

Our understanding of microbial growth and how to control it gives us the ability to preserve food for a long period of time. Without that understanding, we will not be able to preserve food for long periods. It is highly biodegradable. We are all familiar with yogurt or curd that is made by microorganisms using milk. So, that is the best example that all of you are familiar with, probably from day one.

Many kids are unable to digest milk and they are able to digest curd because the fact is that the microorganisms are doing half the job. So, the ability, like I said, to digest complex organic compounds like lactic acid is a good example of how microorganisms can help in the digestion of certain products. So, dairy products, probiotics, many of these things that you see even in the market, are all manufactured using microorganisms.

You are all familiar with cakes and bread and pastries and all of these things, all these foods are based on fermentation by microorganisms like yeast. And then you have beverages. Alcoholic beverages are all made by fermentation of different organic materials; it can be wheat, it can be malt, it can be rice, it can be any type of material can be used.

When we talk about water and wastewater treatment, in water treatment, the most essential process; you can eliminate every other treatment process, but the one process that you cannot eliminate in water treatment is disinfection. And disinfection has just one objective and that objective is to eliminate pathogenic microorganisms which may be responsible for causing various diseases, something as mild as a stomach ache, all the way to very serious diseases like hepatitis and so on. So, cholera, hepatitis, all these are waterborne diseases. So, water treatment and disinfection are some of the most essential processes just to eliminate pathogenic microorganisms.

In wastewater treatment, we are looking at the beneficial aspects of microorganism growth. So here, we are utilizing aerobic heterotrophic microorganisms and utilizing their ability to convert complex organic matter into sludge and biomass; and that biomass can then be converted to biogas. So, that is another one. Now, imagine that you have certain areas of soil, of beaches and you know, there are examples of oil spills and so on. So, all this organic material which is spread across acres and acres of land and has contaminated soil can be bioremediated quite easily and inexpensively, without any toxic side effects, you might say, and that is bioremediation. So, this is a major growing area where we have applications of microbiology.

A new area that has emerged is bioleaching. Now, I want to extract metals from certain products; so, for example, mobile phone batteries, mobile phones themselves. These can be bioleached. There are industrial level examples as well as lab level examples where these materials can be extracted; the metal, for example, cobalt, copper, gold, uranium; all these metals can be extracted from various types of starting materials. The starting material, as I said, can be mobile batteries or ore, or any of the other types of materials. Bioleaching is another effective and cheap method for doing that.

You can also use it for degrading any number of contaminants. We are dealing with synthetic organic compounds as well as natural compounds like oil-based compounds. So, these pollutants, whether they are of natural origin or anthropogenic origin, can be biodegraded. And all you need to do is acclimatize the bacterial species that are capable of degrading these pollutants and then apply it to certain conditions, in either natural or engineered environments.

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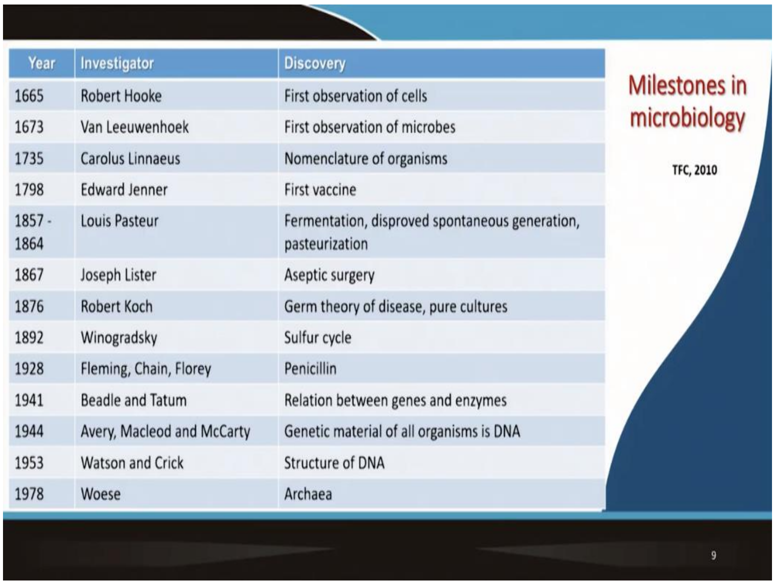

So, after having seen all the applications, not really all, but some of the applications that are possible in environmental microbiology. Let us get an idea about the history, some of the major milestones in microbiology. This discipline has matured a lot in the last 300, 350 years or so. And the first one, the first major milestone that I have; this is a sort of arbitrary selection from the textbook, and I have chosen these based on their importance and their relevance to what we are doing.

So, 1665 is the first one, the first milestone; and that was Robert Hooke when he was able to observe microbial cells or just cells. And then 1673, we have Van Leeuwenhoek. He was able to invent a sort of the handheld microscope, where he was able to make observations of microorganisms; and his drawings and so on are still available in the text and so on. Then, we come to 1735, when Carolus Linnaeus came up with the nomenclature of organisms; and what we do today is still very much the same.

And 1798, we have Edward Jenner, who created the first vaccine; and that was the smallpox vaccine. And that has obviously had a major impact on health care and so on. Then we come to 1857.

From the period of 1857 to 1864, Louis Pasteur was basically a giant in microbiology. Several things have been accredited to him, including fermentation, pasteurization. He was able to disprove the theory of spontaneous generation. People at that time used to think that life can begin without any other life form, and he was able to disprove that.

Then comes 1867, when Joseph Lister was able to enunciate the principles of aseptic surgery. So, prior to that, there were too many deaths, too many fatalities on the operating table, because people had not yet understood the importance of aseptic conditions for surgery and so on. So, having described these principles, the number of fatalities, in surgery basically was reduced tremendously.

Then we come to 1876, Robert Koch formulated the germ theory of disease and he was able to show how cultures can be kept in pure form, how you can isolate species and maintain pure cultures. All these have extremely high relevance to what we do today, both in medicine and environmental microbiology and so many other fields.

Then comes 1892, when Winogradsky was able to describe how sulfur is recycled in nature by microorganisms. So, one of the major biogeochemical cycles is sulfur and sulfur is one of the elements. It is an essential nutrient and one of the most important elements. And how it is recycled in nature by various groups of bacteria; he was able to show that in lab experiments as well as describe what happens in nature. So, this was again a very significant milestone; and we will be looking at it in detail in one part of the course, in one of the topics.

Then we come to 1928 when Fleming, Chain, and Florey discovered penicillin; and they were able to define the importance or rather the relevance of penicillin as an antibiotic and its ability to destroy bacteria.

Then we come to 1941, Beadle and Tatum; they were able to describe the relationship between genes and enzymes. We are going to see in subsequent chapters that each gene is defined in terms of the product it generates. So, this relationship was described by Beadle and Tatum.

Then we come to 1944. So, 1944, we have Avery, MacLeod, and McCarty, where they were able to prove that all living organisms have DNA as the genetic material.

The structure of the DNA was described by Watson and Crick in 1953.

And Woese was the one who was able to describe the fact that there is a certain group of bacteria called archaebacteria and these are extremophilic bacteria. They do not exist in normal environmental conditions that we are used to. So, he was able to describe these kinds of bacteria. And on the basis of that, on the basis of his work with archaebacteria, he was able to come up with a classification that is now considered the basis of microbiology these days. So, that was in 1978.

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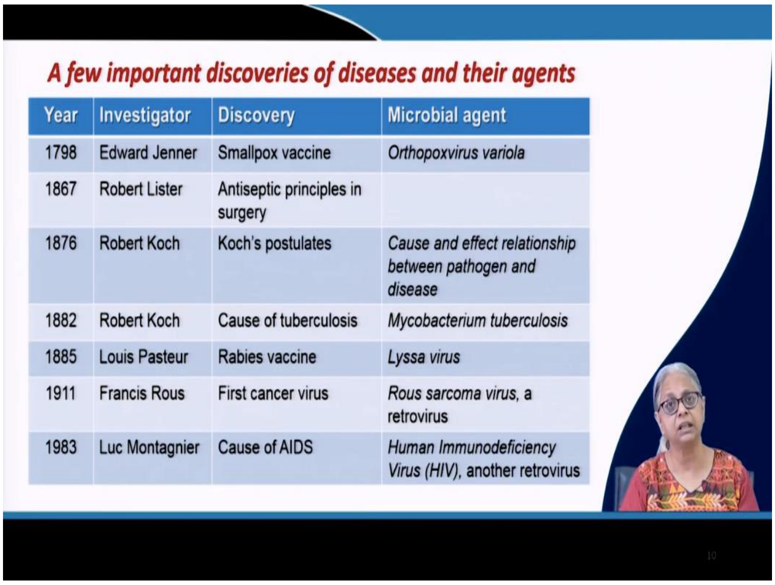

I have listed a few important diseases and their agents over here. So, I have already mentioned most of these things.

I will come to 1885, with Louis Pasteur who discovered the rabies vaccine as well; and the causative agent of that was Lyssavirus.

And then 1911, we have Francis Rous who discovered the relationship between cancer and virus. So, today, most people know that the root cause of certain cancers is due to viruses, viral infections. The Rous sarcoma virus is a retrovirus. And I will come to the definition of retroviruses. Retroviruses are not the usual virus, and we will come to that; they kind of do the opposite of what other normal viruses do. And just to make it clear, the Coronavirus is also a retrovirus and so is the HIV virus. So, these retroviruses; I do not know if it is true or not, but they maybe harking back to a very old point in the evolution of life on the planet. These retroviruses may be reminders of what may have happened at the time. So, anyway, without going into all of those details; 1983 we have the causative agent of AIDS, which is HIV; and it is another retrovirus. And, we need to realize that we have very poor immunity against many of these retroviruses.

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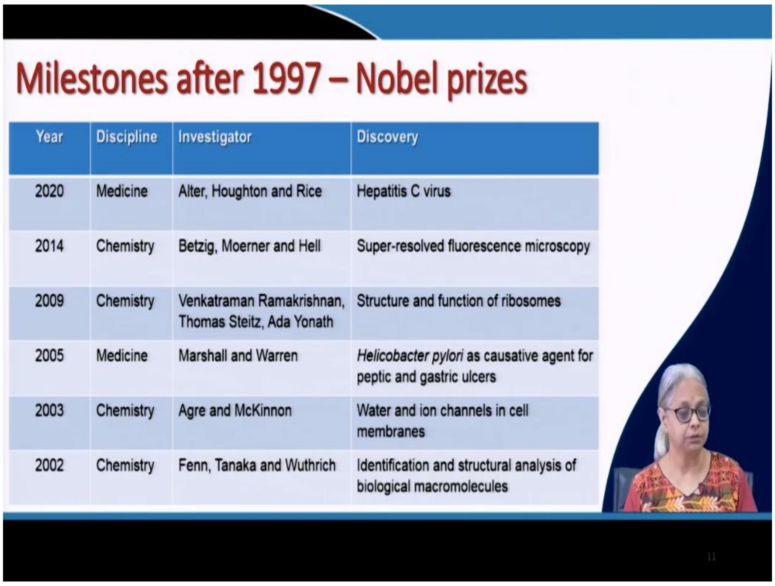

I have a few more milestones after 1997 because the slide ended in 1997 with Prusiner and prions. So, starting from the bottom, 2002, the Nobel Prize for chemistry was given to a group of scientists Fen, Tanaka, and Wuthrich for identifying and understanding the structural behavior of biological macromolecules.

In 2003, we have Agre and MacKinnon, who were able to demonstrate the presence of water and ion channels in cell membranes. Now, these water and ion channels in cell membranes are very important. You might think that water can pass freely through the cell membrane; that is not true. For all the water that is required, it requires a specific channel. So, we have what are called aquaporins that allow water to come in and out of a cell.

Then we come to 2005 and Marshall and Warren were able to identify Helicobacter pylori as the causative agent of peptic and gastric ulcers.

In 2009, in chemistry again, we have Ramakrishnan, Steitz, and Yonath who were able to describe the structure and function of ribosomes. Ribosomes are extremely essential organelles in both, prokaryotic and eukaryotic cells and we will be looking at some of these points later as we go along.

In 2014; chemistry; Betzig, Moerner and Hell, came up with a new method super-resolved fluorescence microscopy. For those of you who are familiar with this, fluorescence microscopy has come into its own in the last 20 to 50 years maybe; maybe more. Fluorescence microscopy is a type of optical microscopy; and those who know, you might know that optical microscopy has a limit; you can magnify only 1000 times. Fluorescence is part of optical microscopy; but with super-resolved fluorescence microscopy, they have been able to go down to the nanometer level, which means 100,000 times or even more magnification. So, this is a huge achievement. And even though I am not going to be focusing on it, it is very relevant to most of us who use optical microscopic methods for looking at microorganisms. These are quick and easy methods and they have enormous potential for the identification of species and so many other things. Then we come to 2020 in medicine, Alter, Houghton, and Rice discovered the hepatitis C virus. The one that we are all familiar with in India is hepatitis A, which is foodborne and waterborne, but hepatitis C is also a very serious pathogen. And that is the most recent Nobel Prize. I think I will stop at this point. And we will take a break here.