

Introduction to Complex Biological Systems
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Lecture 21
Introduction to cells

Welcome to week 5. So, in this week's lecture we are going to look at the unit of life which is cell. So, you have already seen this and, but this is a good time to recapitulate this, the levels of organization of life forms.

The first or the bigger level will be that of a biosphere which includes all living entities of the universe or if in this case we will consider it as the earth. So our earth considers the biosphere which accounts for all the organisms on this planet. The next level of organization is an ecosystem which consists of an interacting community of different life forms. So a very good example will be a rainforest and in this rainforest we have individual organisms which are life forms or species such as plants, insects, birds, animals and microbes.

If we consider multicellular organisms like us like humans then they consist of organs so we have all sorts of organs and these organs have specialized functions examples will be your heart lungs eyes. Now each of these organs are made up of tissues so these tissues again perform certain specialized functions. So if we consider the organ eye. It will have three different types of tissues. One will be light sensitive tissue, another will be support tissue, and the third one is the retina. Now, if we zoom into each of these types of tissues, then they are made up of cells, which constitute the smallest unit of life.

So microbes, they are unicellular. So they are a single cell organism. But if we talk about animals, birds, insects, plants, these are all multicellular. They will have these organs and tissues and for them also the smallest unit of life will be a cell. If we consider eye then together for all these tissues, if we look at all the different types of cells, it turns out that there are 58 different cell types, which can be grouped into these six different types, such as photoreceptor, horizontal, bipolar cells, amacrine cells, retinal ganglion, and non-neuronal cells.

So there is a very interesting project that is going on called the Human Cell Atlas, which aims to map all the different cell types that are present in a human being. So this particular data is taken from this paper where they mapped the different cell types in a human eye and it turns out that there are 58 different cell types that are present. So if we zoom in further, then for eukaryotic cells, we will see that they are made up of different organelles. So these are distinct structures within the cell and they perform different functions. We will see those in more detail in today's lecture.

If we zoom in further, so examples of organelles will be nucleus, mitochondria, etc. If we zoom in further, then these are made up of molecules. We have already seen these molecules, nucleic acid, protein, lipid, carbohydrate, etc. So in the first four weeks, what we have learned was mostly focusing on these molecules and these are called the molecules of life.

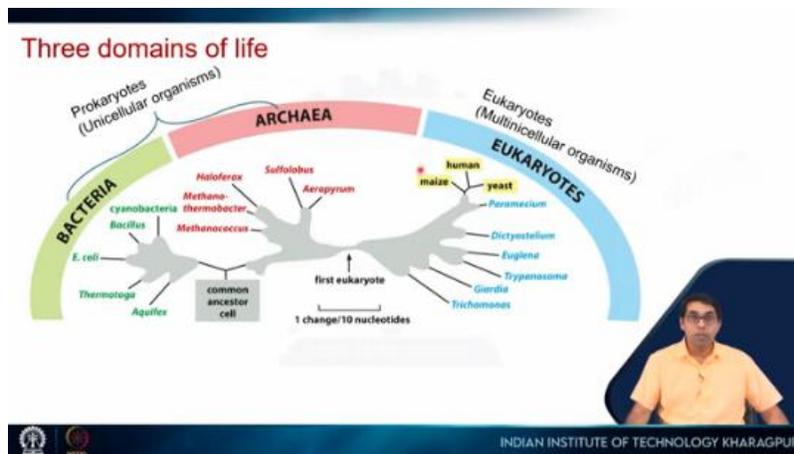
And as you may have seen that these molecules are very common in all life forms, whether it is bacteria or whether it is us, right? So we have the same type of DNA, proteins are made up of the same type of amino acids, so on and so forth. Now, from this week onwards, we are going to look at these higher levels of organization. So in week five we will focus mostly on cells, which is the smallest unit of life.



And then from week six onwards, we will look at these higher order organizations. So let's look at these various life forms that are present on this biosphere, which is Earth. If we look at all the life forms, they can be grouped into these three domains. So these are called the three domains of life. First one is called bacteria, the second one is archaea and

the third one is eukaryotes. Bacteria and archaea are unicellular organisms and they evolved much longer before the eukaryotes evolved. So I will discuss the evolution of life in more detail in another week's lecture. So briefly bacteria and archaea both are unicellular and together they are called prokaryotes.

Eukaryotes can also be unicellular but they can also be multicellular so all plants and animals are eukaryotes. So let's look at the scale of things in terms of the dimension. So if you look at your thumb as it is just shown here, we are looking at something in the scale of centimeters, so this is 20 millimeter which is 2 centimeters if we zoom in to a particular part of your thumb 10 times, then this is 2 millimeter and we can see all these ridges. So these ridges are the ones which actually form the fingerprint of your finger. If we zoom in tenfold further, then you can start seeing these small structures which are cells. We zoom in ten times further.



Now you can actually see the outline of a cell. So this is 20 micrometers across. So you can see from this that these cells are roughly 10 micrometers in size. So this end to this end will be around 10 micrometers or 15 micrometers and here we can see all these different organelles.

So the two big prominent organelles can be seen here. So this is the nucleus and that is the mitochondria. So if we zoom in 10 times further, we can see mitochondria. We will see that mitochondria is something that is very important. We will discuss more about mitochondria when I talk about respiration.

So you can see there are all these small dots which are floating around. So if we zoom in tenfold further, you can see that those dots are ribosomes. So on those ribosomes, so this is the mRNA and on that protein is getting synthesized. We zoom in further; we can see more details of the ribosome. We zoom in further than we can start seeing the atoms and this is two angstroms 0.2 nanometer or two angstroms, we can actually see the atoms. So there are all these different techniques which can be used to see at this different scale length. So I will talk about these techniques in more detail in the next lecture.



So it turns out that cells are very small. They are in the range of 10 micrometer size, but that's a eukaryotic cell. If you think about bacterial cells, they will be even smaller. So you may ask that why cells are so small? Why do we have to make the cells so small?

We cannot even see it with the naked eye. One of the explanations is that by making something smaller, we can increase the surface area. So, take for example, this cube. So, let us say it is 5 by 5 by 5 in some units so the volume of this cube will be 5 cube.

So, 5 times 5 times 5, that is 125. And the surface area will be, so one of these faces will be 5 times 5, that is 25. Now, there are 6 faces. So, 6 times 25. So, if we divide that, we get 1.2.

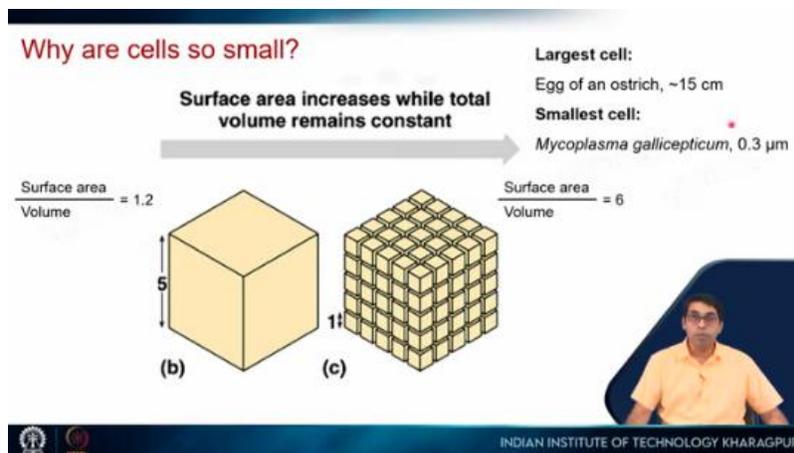
Now, instead of having one large cube, what we can do is we can divide this into multiple cubes where each cube has unit 1 in length, breadth and height. The volume of this cube will be 1 and the surface area will be, so one of this areas will be 1 times 1, so that is 1 and then there are 6 faces, so it will be 6. So 6 by 5 is 6, right? And then you have the

same 125 number of cubes, so you multiply and divide by 125, so it remains as 6. So for this, the surface area to volume becomes 6, right?

So this is 5 times of this. For the same material, we have increased the surface area to the volume ratio by 5 fold. And it turns out that surface area or the membrane of the cell plays a very important role. So, we will see that in the following lectures. We have seen that when I discussed membrane proteins.

So, these membrane proteins are embedded on the membrane and they do their function. So, you need a large surface area. So, that determines the size of a cell. But again, this does not mean that all cells are of the same size that is 10 micrometers in dimension. The largest known cell is that of an egg of an ostrich.

So, it is 15 centimeters in width and around 20 centimeters in length. So, it is a very big cell. On the other hand, the smallest cell that is known is around 0.3 micrometers in size. So you can see that there is a large variation in the size of cells and it depends completely on the function that cell is going to perform.



So here are some typical examples. So this is a bacteria *Lactococcus lactis* and this bacteria is used to produce cheese. So it is used a lot in the milk product industry.

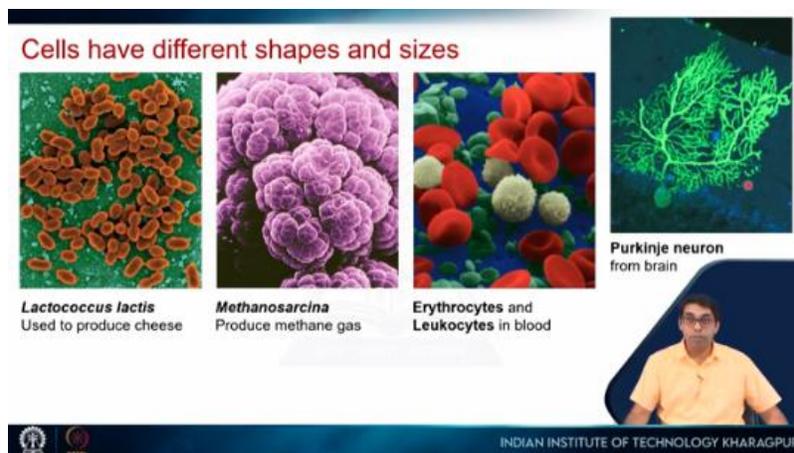
This is another bacteria, this is a bacteria that is an archaea. So it forms these colonies like structures and it is called *Methanosarcina*. This type of archaea, they are found in many places. One of the prominent places is the gut of cattle and they produce their energy by reducing carbon dioxide and produce methane gas. So they turn out to be one

of the largest producers of methane gas and methane gas is a greenhouse gas, which results in global warming.

These cells are found in our blood. So the red ones are erythrocytes and the white ones are leukocytes. So this is a red blood cell, this is white blood cell. These are false colors, but they have been colored so that we can see them. So we have already seen these red blood cells.

They carry hemoglobin, which is very important for transport of oxygen. We will see about these leukocytes in more detail when we talk about our immune system. So there are different types of leukocytes and they have different functions and they form a very important part of our immune system. This is a neuronal cell. So it's a Purkinje neuron.

It is found in our brain. And you can see that its structure or morphology is very different from these cells. So this neuron has all these branchings and it makes connections. So this particular neuron can make almost 100,000 different connections with other neurons. So cells come in all sorts of shapes and sizes.



Now, again, broadly, if we look at cells, which I have already shown you before, they can be either prokaryotes or eukaryotes. So what does that mean? Prokaryote means these are single-celled organisms and these are all bacteria. So this can be eubacteria or archaea. Eukaryotes, on the other hand, can be single-celled or can be multicellular.

Pro means before and eu means true. True means something that is present. What is present? Nucleus is present. So prokaryotes are the organisms which evolved before the nucleus.

So they do not have a nucleus and eukaryotes have a nucleus. So that is why it is called true that the nucleus is present. So the general architecture of these two cell types will be something like this. This is a bacterial cell.

All cells are prokaryotic or eukaryotic

- **Prokaryote**: single-celled organisms, and all are bacteria.
- **Eukaryote**: single-celled or multi-cellular organisms

- **Pro** = before
- **Eu** = true
- **Karyon** = nucleus

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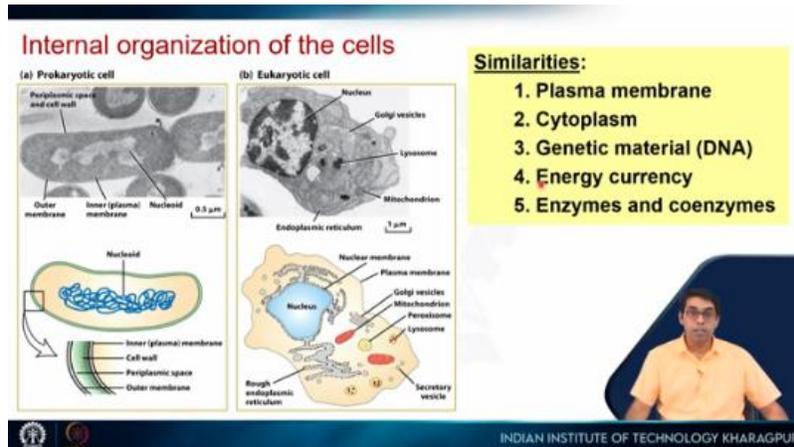
So what we see here is the plasma membrane and there is a cell wall. So we have this inner plasma membrane. So if we zoom into this. We have an inner plasma membrane and then we have a cell wall and then we have this periplasmic space and then outer membrane. So we will talk about this in more detail in later lectures.

On the other hand, a eukaryotic cell looks more complex. So it is much bigger in size than a bacterial cell. So you can see that this is 0.5 micron in scale and this is 1 micron. So this is much bigger. So you have to actually make it twice the size of this if you put it in this scale and you will see it is much bigger than a bacterial cell.

So here we see the nucleus, we see all these different organelles. So the architecture of a eukaryotic cell is much more complex compared to a bacterial cell. What we see here is the DNA of the bacteria. The DNA of the eukaryotic will be present inside the nucleus. So there are of course some similarities.

Both have plasma membranes. They have cytoplasm. So this part or this part is the cytoplasm. The genetic material is DNA in both cases. They use energy currency.

Typical energy currency will be ATP. They use enzymes and coenzymes to perform various tasks inside the cell to carry out all the biochemical reactions. But then there are of course several differences. One difference is that no membrane-enclosed intracellular compartment is present to house the DNA. We saw that in the previous slide.



In case of eukaryotes, there is a well-defined nucleus which houses the genetic material, which is the DNA. Prokaryotes or bacterial cells lack most of the complex membrane-bound internal organelles. So there is no mitochondria, there is no ER, there is no Golgi, but this type of complex membrane-bound internal organelles are present in eukaryotic cells. Prokaryotes have a single circular chromosome whereas eukaryotes have paired chromosomes and we will see examples that in many cases these are linear chromosomes.

So here the chromosome is a single chromosome but in this case we have multiple chromosomes. So the DNA is divided into multiple molecules and these are linear molecules. Prokaryotes lack histone proteins. Eukaryotes have histone proteins. I will show you what is a histone protein in the next few slides.

And finally, prokaryotes have a peptidoglycan cell wall. Plant and fungal cells have these cellulose and chitin in the cell wall, but no such cell walls are present in animals. So we do not have cell walls. And this is something that becomes very important because we can target this peptidoglycan cell wall to kill pathogenic bacteria. Because since we do not have that, any molecule which targets a cell wall will not cause any harm to us.

But of course, we have to remember that they will kill the bacteria or the good bacteria which are present in our body. So, I mentioned that in eukaryotes, DNA is present as paired and linear molecules which are called chromosomes. So this is a eukaryotic cell. This is the nucleus.

Differences between prokaryotic and eukaryotic cells

Prokaryotic cells	Eukaryotic cells
No membrane-enclosed intracellular compartment to house genetic material (DNA)	Have <u>well defined nucleus</u> (membrane-enclosed intracellular compartment) to house genetic material (DNA)
Prokaryotic cells <u>lack</u> most of the complex membrane bound internal organelles	Eukaryotic cells have <u>well defined and complex membrane bound internal organelles</u>
Prokaryotic cells have a <u>single</u> circular chromosome	Eukaryotic cells <u>have paired chromosomes</u>
Prokaryotic cells <u>lack</u> histone proteins	Eukaryotic cells <u>have histone proteins</u>
Prokaryotic cell wall <u>has</u> <u>peptidoglycan</u>	Plant and fungal cells have both cellulose and chitin in cell wall. No such cell wall in animal cells



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Inside the nucleus, chromosomes will be present like this. So if we zoom into this, we can see the DNA. But this DNA is present in a highly condensed form like this. This is something that happens in a particular state of the cell cycle which is called mitosis. So I'll talk about mitosis in more detail in the third lecture of this week.

If we consider the human genome, then our DNA is divided into 23 fragments. And depending on the size, they are numbered as 1, 2, 3, so on and so forth. So, 1 is the largest chromosome and 22 is the smallest chromosome. The last one, the 23rd chromosome is actually the sex chromosome. So, in all this 1 to 22, they are the same chromosome and they are present in

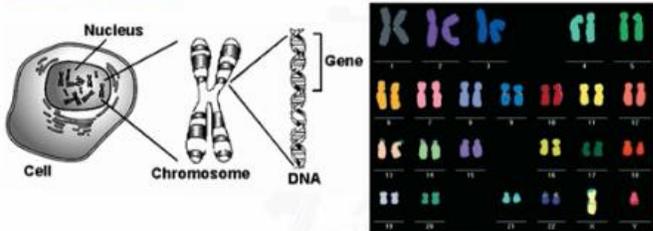
two copies. It turns out that one comes from each parent. The sex chromosomes are different. One is X, the other one is Y. So if an individual has both as X chromosomes, that will be a female. If one is X, one is Y, that will be a male.

So I will discuss this in more detail in the third lecture. Now, I would like to point out something that is very interesting. So if you look at this last chromosome, the 22nd, which is the smallest one, It has roughly 48 million base pairs and if we stretch it out like

this, then end to end its length will be 1.5 centimeters. So you can easily calculate the distance between the base pairs and you multiply that by 48 million.

So you can figure out what will be the length of this chromosome if we stretch it out completely. In mitotic state, this chromosome is compacted like this and its length is 2 micrometers. So there is a compaction of 10,000 fold. How do cells achieve this huge amount of compaction? So in a mitotic state, the compaction is the largest, but even if we consider an interphase, there also the compaction will be thousand fold, that of this length.

Chromosomes



- Chromosome 22 contains 48 million base pairs.
- End to end, its length is 1.5 cm.
- In mitotic state, it is compacted to a length of 2 μm . A compaction of 10,000 fold.

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So how is that achieved? That is achieved by something using the histone proteins. So first of all, you have to consider this DNA molecule. So if you remember, DNA has this phosphate backbone, which is negatively charged, which means that DNA is a highly negatively charged molecule. So this molecule, since it is highly negatively charged, will expand out.

So if we try to compress it into a small volume, it will repel and it will expand out. So the first thing that you have to do is neutralize this charge on the DNA and that is done by a set of proteins called histone proteins. So histone proteins are the surface of the histone proteins and will be highly positively charged. And you can imagine based on what we have learned so far, what type of residues should be present to make it positively charged.

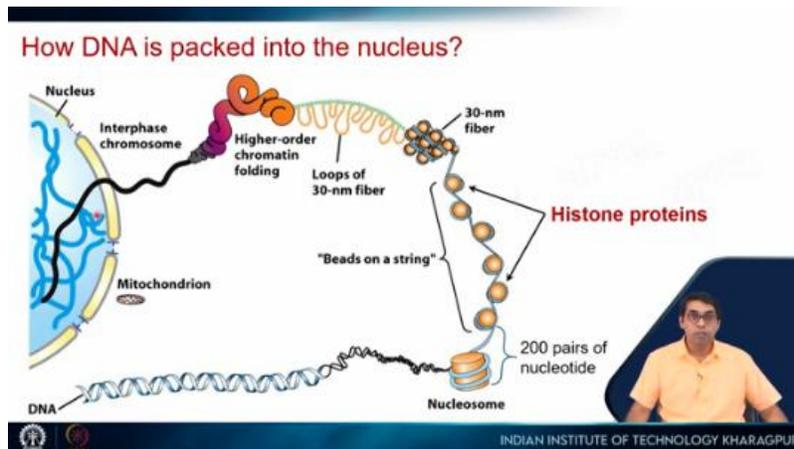
So there has to be basic residues like arginine and lysine and histidine. So histone proteins actually have a lot of arginine and lysine and histidine on the surface. The DNA is wrapped around the histone proteins like this. So it turns out that there are eight

molecules of histone proteins which come together to form this cylinder-like structure on which the DNA is wrapped and this neutralizes the charge.

So this to this, this whole histone protein and some part of the DNA which is extending out, this is called a nucleosome. And the DNA length that goes from here to here, considering whatever is wrapped here, will be roughly 200 pairs of nucleotides. So this is a nucleosome. If you look at the DNA, it looks like a bead on a string. So we have this long string

and on this, you have these nucleosomes which form small bead-like structures. Now, this is almost neutralized. So this can be compacted like this and more proteins come in to form compact structures like this. So normally DNA presents something like that. In case of mitosis, higher order compaction occurs and the DNA becomes really compact.

So this way we can, or cells, pack this highly negatively charged molecule into a very small volume of the nucleus. So histone proteins look something like this. So you can see it's mostly alpha helical. These are the proteins and the DNA is wrapped around the histone protein.

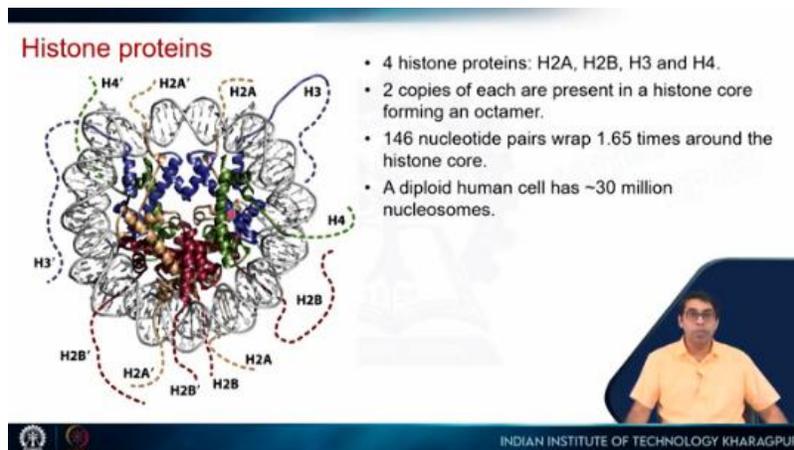


So there are four types of histone proteins, H2A, H2B, H3, and H4 and each of these are present twice. So there are two copies of each of these present, which means that there are a total of eight proteins and together they form an octamer, which forms this cylindrical structure, on which 146 nucleotides wrap around this histone 1.65 times. So it

goes around like this and then some more. So that is 1.65 times and that is 146 nucleotide base pairs.

A deployed human cell will typically have 30 million nucleosomes. So one more thing that I would like to point out is that this, you can see that the histones are highly structured molecules on which the DNA is wrapped around. However, the end terminus of the histone is shown here, like these dotted lines. So these dotted lines indicate that at this end terminus, there are several residues, maybe around 10 residues roughly are highly disordered, which means that they do not form any structure.

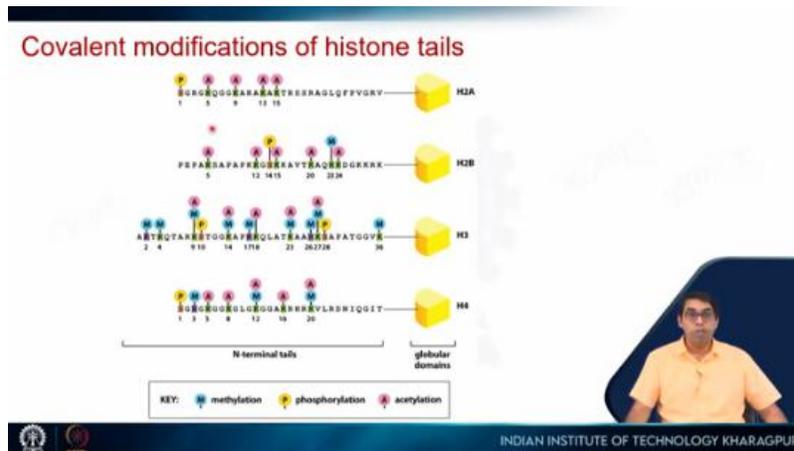
They do not form any secondary structure and they do not pack against this rest of the protein. So they are disordered means they can flop around like so and this disordered part plays a very important role. So that disordered part is shown here. So this is the folded histone.



So this is H2A, H2B, H3 and H4 and their N-terminus disordered part is just shown here. These N-terminus part undergoes covalent modification. So these are called post translational modification because after translation, this protein is formed, but there are other enzymes which will come and add certain functional groups on the side chain of a protein. For example, P is a phosphorylation.

So a phosphate group is added. We have already seen phosphorylation. We saw that kinase enzymes add phosphorylation. A is acetylation, M is methylation. So there are again enzymes which will add these modifications on very specific amino acids on these

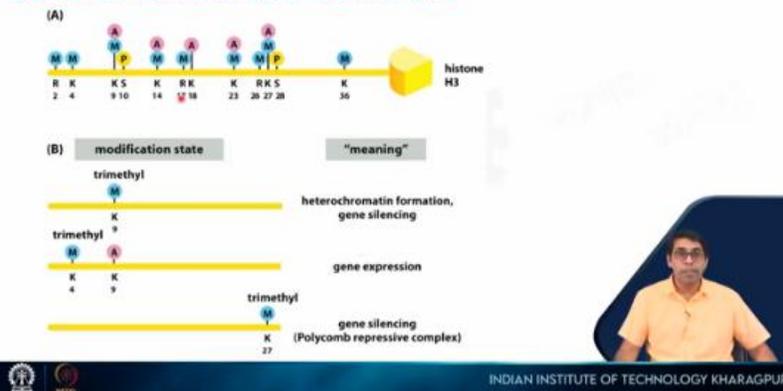
histones and there are enzymes which will remove this. Just like in case of phosphorylation, we saw that kinases will add the phosphate group and phosphatases will remove the phosphate group. Similarly, there are acetylation and deacetylation or methylation and demethylation that are done by different sets of enzymes. It turns out that a combination of this acetylation and methylation indicate certain signals to the cell.



One such example is shown here. So what is the meaning of this? For example, if a methylation happens here, it means that heterochromatin formation is favored so that whatever part of the DNA is there, it will be tightly wrapped and it will be not exposed to the polymerase which means that if any gene is present in that part of the DNA. It will not be accessible to the polymerase so no mRNA synthesis will happen. So that is gene silencing. On the other hand other modifications can indicate gene expression so the chromatin will open up and it will be accessible to the polymerases and other proteins.

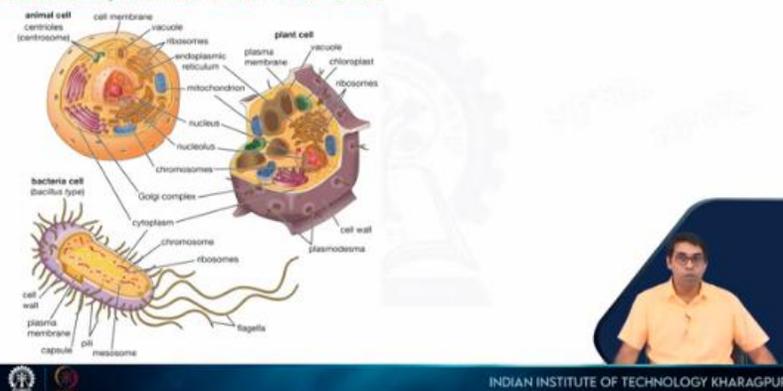
So these type of modifications can also control expression and repression of genes. So as I mentioned that there are two types of cells prokaryotes and eukaryotes and these are some of these shown here. So bacterial cells will typically look like this, eukaryotic cells or animal cells will look like this and the plant cell will look like this. So these are both eukaryotes, plant cells will have a cell wall, bacterial cells will have a cell wall, and no cell wall in animal cells. So what is the function of a bacterial cell wall?

Covalent modifications of histone tails



It lies outside the cell membrane in nearly all bacteria except mycoplasma, the smallest one that we saw, and some archaeobacteria.

Bacteria, Animal and Plant Cells



They have two important functions. First, they maintain the characteristic shape of the cell and they prevent osmotic lysis. So there will be mismatch of salts and other molecules inside and outside and that can result in lysis of the cell.

Bacterial Cell Wall

- Lies outside the cell membrane in nearly all bacteria (except mycoplasma and some archaeobacteria)
- Two important functions:
 1. Maintains the characteristic shape
 2. Prevents osmotic lysis

So that type of lysis is prevented mechanically by this bacterial cell wall and that is something that becomes very important for us. So if we look at the cell wall, so we zoom into this cell wall of bacteria, it is formed of sugar and amino acids. So polymers of sugar and peptides and this chain that you see is made up of two sugar molecules.

One is N-acetylglucosamine or Glucanac and the other one is N-acetylmuramic acid or Mur2Ac. So these are present alternately and they are linked by these beta 1,4 glycosidic bonds. So one chain is here, one chain is here, one chain is here. So you can think of it like a fence where we have these wires, but then you have to connect those wires.

So you have to cross-link those wires and that is done by this polypeptide chain. So this is a pentaglycine and these are four amino acids, which are L-alanine, D-glutamic acid, L-lysine and D-alanine. So just see that here. D forms of the amino acids are used. So there are many ways, there is this whole biosynthetic pathway by which the cell wall is synthesized.

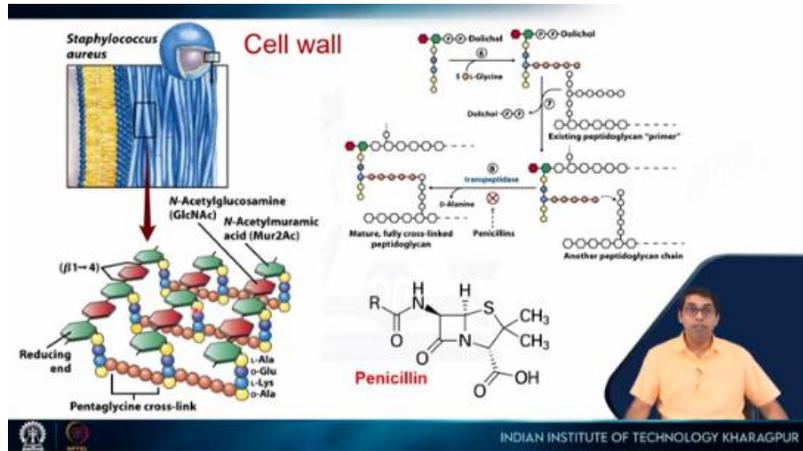
I will focus only on the last part. So what we have is this polysaccharide chain and so that is shown here. From there, this is hanging out and then this is the pentaglycine. This is another chain.

In that we have these five amino acids, the last two are D-alanine and D-alanine. There is this enzyme called transpeptidase where this glycine will attack it and one, the terminal D-alanine will go out. So it goes out and you form this cross link.

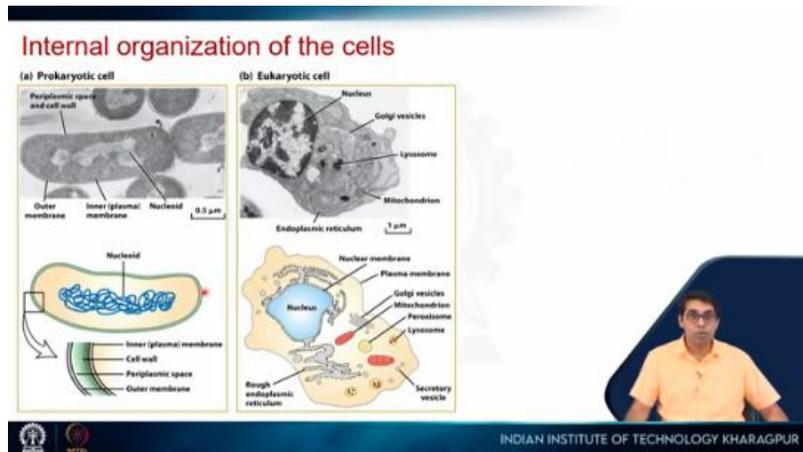
So this cross linking is formed. Penicillin is an antibiotic which inhibits this transpeptidase. So we have already seen enzymes. We have seen there are inhibitors which can form covalent linkage with the enzyme. So penicillin is something which forms a covalent linkage with this enzyme and it will completely block this enzyme.

If this enzyme is blocked, this means that no cell wall synthesis can happen. If cell wall synthesis does not happen, the bacteria will undergo lysis, osmotic lysis. So penicillin can kill bacteria and it is a very good antibiotic because this is not present in our cells, it is only in bacterial cells. But you have to remember that taking too many antibiotics can cause harm because it can kill the good bacteria that are present in your body, for

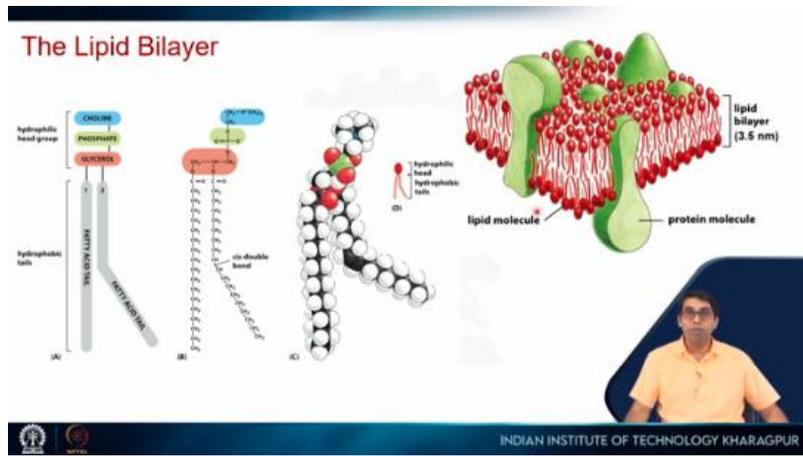
example in your gut. So coming back to this, this is the prokaryotic cell. We have already seen the features of this and it is quite simple, but the eukaryotic cell is much more complex and it has all these internal organelles.



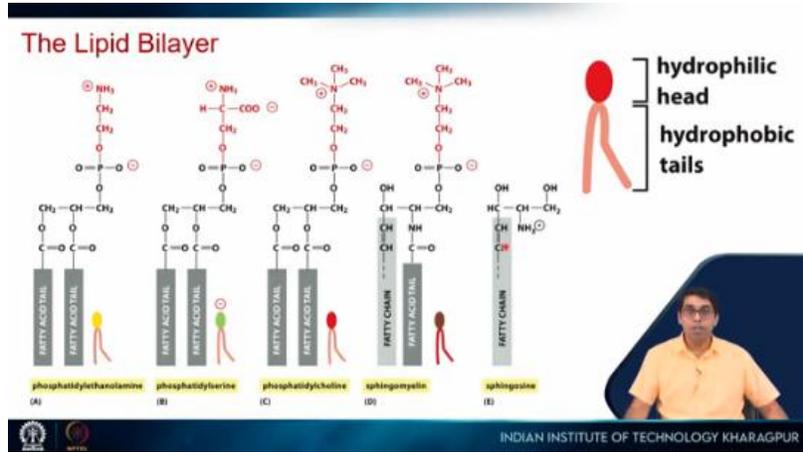
But one important thing that is common for both is the plasma membrane so this plasma membrane that we have for the one that encloses the cell. Plasma membrane is formed by a lipid bilayer. So we have already seen when I discussed membrane proteins. So this is a lipid molecule and it has this charged head group and this fatty acid side chain.



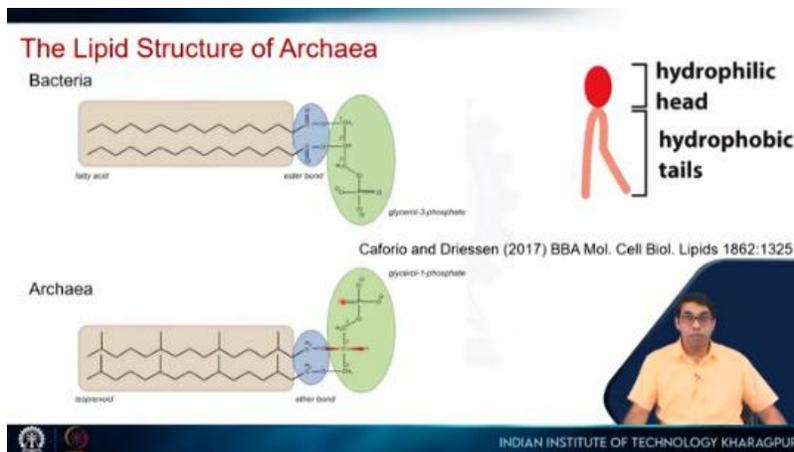
So it forms a bilayer like this on which these membrane proteins are embedded. So it turns out that there are all these different types of lipids. So you have Phosphatidyl ethanolamine, phosphatidylserine, choline, sphingomyelin. And we will see that these are all present in the two bilayers of the lipid and they play very important roles. So typically the architecture of a lipid by lipid will be that we have a hydrophilic or charged head group and a hydrophobic tail.



I would like to point out here that this is the typical structure of bacterial and also eukaryotic lipids. But in the case of archaea, the lipids are slightly different. So you can see that the fatty acid side chain here has branches. You can also have cyclic molecules in these fatty acid side chains. This is an ester bond.



So that connects the fatty acid with the glycerol moiety. In this case, it is an ether bond. Here it is glycerol 3-phosphate, here it is glycerol 1-phosphate. So there are some major differences between bacterial and archaeal lipids.

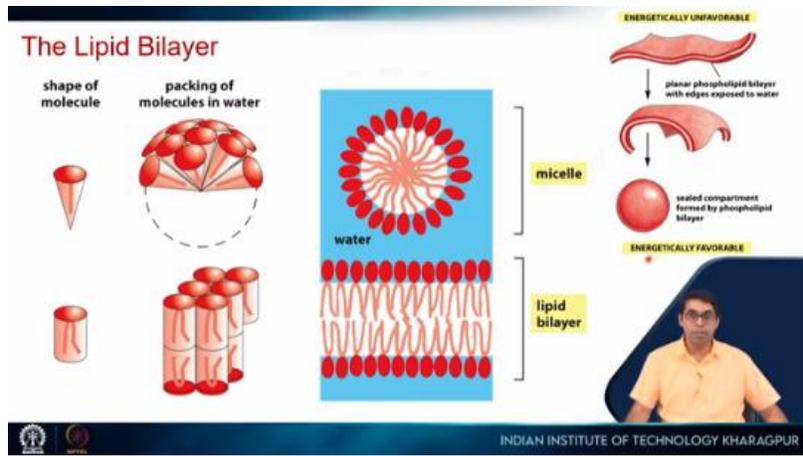


So structure wise, both look like this. So this is something that we normally see for a surfactant. The soap that you use will have a long fatty acid side chain and a polar head group. So there it looks like a cone because there is only one long chain and when you put these molecules in water they will form a structure like this, a spherical structure like this, which is called a micelle. So it's a micelle. But the lipids that we have in our cells have two fatty acid chains and depending on the cis and trans bonds, you can actually have a kink like this.

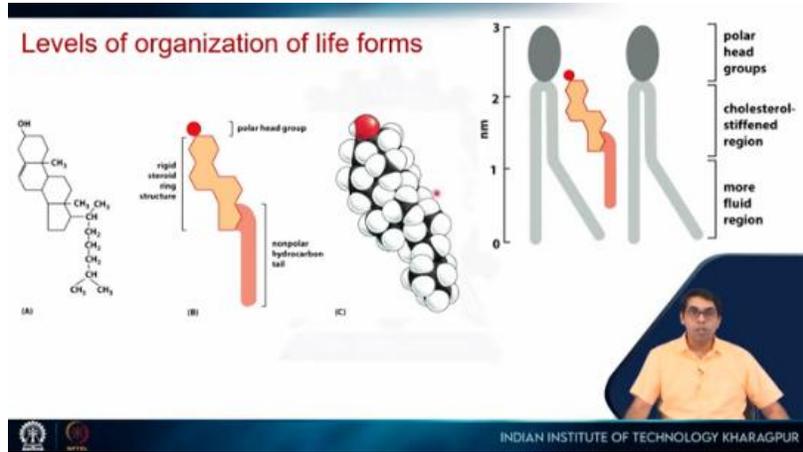
So the shape of this is more cylindrical instead of a cone. So if you have a cylindrical molecule, if you pack them, you cannot form a circle or a sphere like this. So in this case, they pack more like this. So they form a bilayer. Now, if you have a bilayer, this is energetically quite stable.

However, there is a problem that the edges will be exposed to water. So one way you can eliminate that is if you fold it into a complete spherical structure then there are no edges and this becomes energetically favorable. So that is your cell. So whatever is inside will be the inside of the cell and outside will be the outside of the cell.

So the intracellular and extracellular parts are separated by this lipid bilayer. On this lipid, there are, of course, proteins, but there is one more interesting and important molecule, which is cholesterol. So this is the structure of cholesterol. You can see that it has a tiny polar head group, which is this OH group and then the rest is nonpolar.



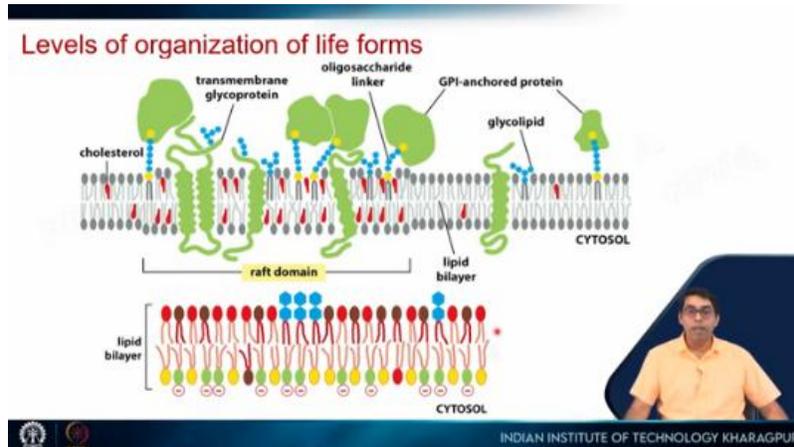
So it is not as big as the lipids. But it sort of spans the hydrophobic part of the chain and the function that this cholesterol performs is it stiffens this region. One of the functions that this cholesterol performs is that it stiffens this region. So this is something that we have seen before.



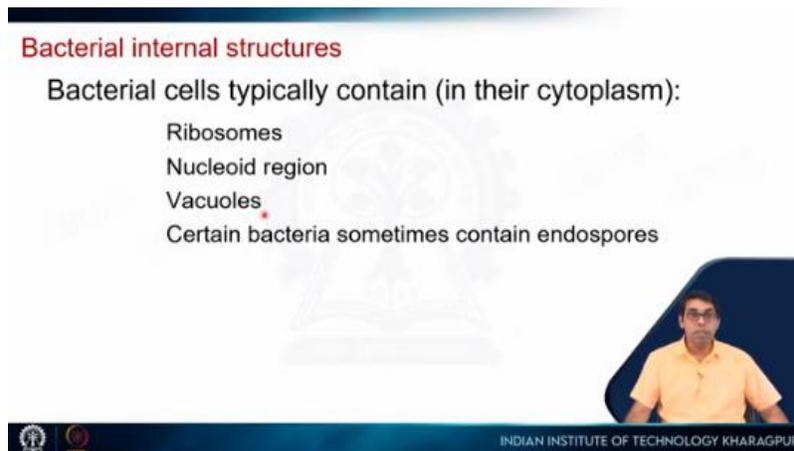
We have the lipid bilayer. On that, we have all these proteins which are embedded. In most cases, they are helical. You can also have beta barrels. It turns out that the regions where proteins are embedded; we find more cholesterol molecules because they tend to make this region more rigid.

These types of rigid regions are sometimes referred to as lipid rafts. It is important to note that the two leaflets of the lipid bilayer do not have the same composition of lipids so the lipids on the outer membrane versus the lipid on the inner side. So this is the cytosolic part and this is the extracellular part. They will have different compositions and this is also something that is important. We will see when we discuss cellular apoptosis. So if

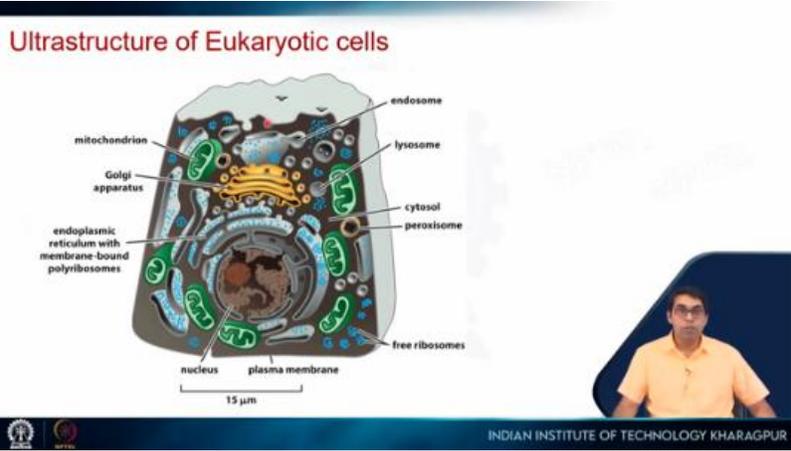
we look at the internal structure of bacteria, they are relatively simpler. There you have ribosomes. There is a nucleoid region which has DNA.



There are some big vacuoles and certain bacteria sometimes contain endospores. So this is the bacterial architecture. It has DNA. Normally it is a singular molecule which is circular. E. coli DNA measures around 1400 micrometers in length and this DNA is coiled extensively. So you can see it's a very coiled structure and RNA and other nucleoproteins, nucleoid proteins are also present which forms this nucleoid apart from this, there can be other smaller circular DNA present which are called plasmids.



Now, let us look at the ultrastructure of a eukaryotic cell. So, a typical eukaryotic cell will look something like this, where we will have a nucleus, attached to the nucleus, we will have the endoplasmic reticulum, then there will be Golgi bodies, there is mitochondria and then lysosomes, paroxysomes and other molecules, other membrane bound structures.



So this table is something that summarizes all the functions of these different membrane bound structures. So you can pause this and go through this table.

Functions of the membrane enclosed compartments	
Cytosol	Metabolic reactions, protein synthesis, cytoskeleton
Nucleus	Contains genome; DNA and RNA synthesis
Endoplasmic Reticulum (ER)	Synthesis of lipids and proteins
Golgi apparatus	Modification and packaging of proteins and lipids
Lysosomes	Intracellular degradation
Endosomes	Sorting of endocytosed material
Mitochondria	ATP synthesis by oxidative phosphorylation
Chloroplasts (in plants)	ATP synthesis and carbon fixation by photosynthesis
Peroxisomes	Oxidation of toxic molecules

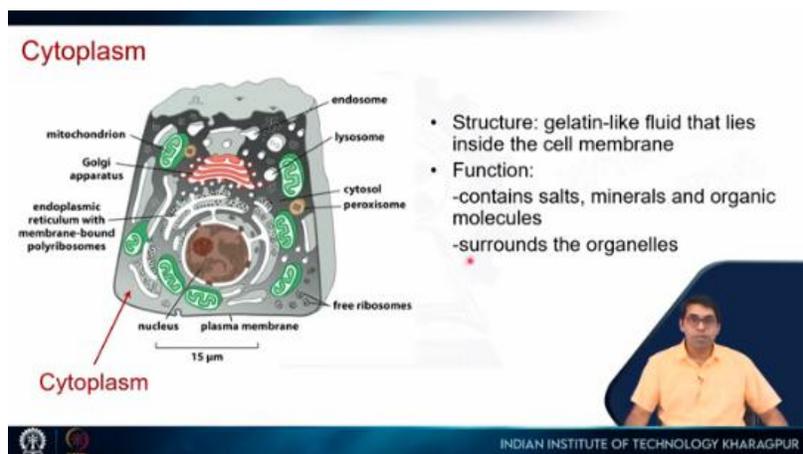
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This table shows the relative volume of these different organelles that are present in a cell. So in this case, it is given for a typical liver cell. So volume wise, cytosol has the largest volume. So it occupies more than half of the cellular volume. Then the next big organelle is mitochondria.

So again, mitochondria is not one, there are multiple mitochondria present. If you consider their total volume, that will be more than 20% or one fifth of the cellular volume. Then rough ER, then Golgi bodies, and these are much smaller. So the nucleus occupies only 6% of the total cellular volume. So you can imagine the level of compaction that is needed to pack the DNA inside this nucleus.

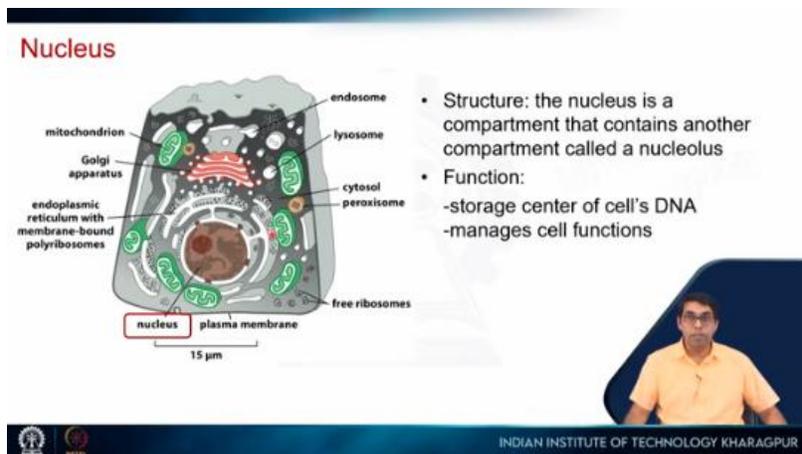
Relative volumes of major compartments in a liver cell	
Intracellular Compartment	Percentage of total volume
Cytosol	54
Mitochondria	22
Rough ER	9
Smooth ER plus Golgi	6
Nucleus	6
Peroxisomes	1
Lysosomes	1
Endosomes	1

So quickly I will go through these different cellular compartments. So cytosol is this rest of the cell inside the plasma membrane. So it is a gelatin-like fluid that lies inside the cell membrane. Its function is that it contains all the salts, minerals and organic acids and this is the place where a lot of biochemical reactions happen. So it surrounds all these organelles.

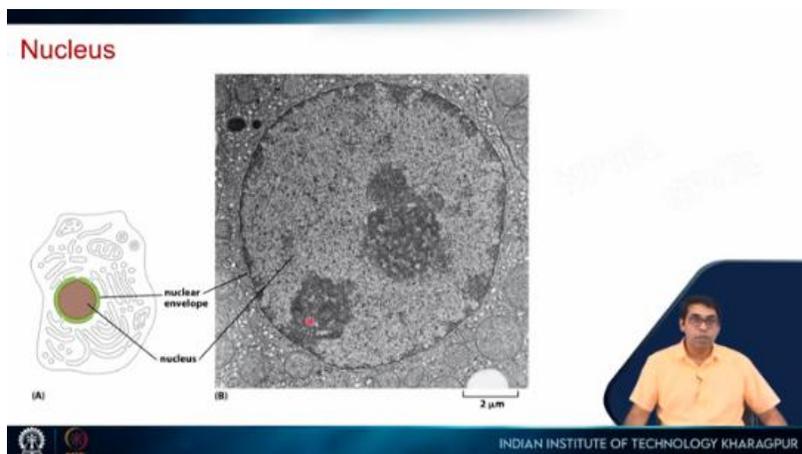


Nucleus is here and it is the one which contains the genomic material. So this is where DNA replication and synthesis of mRNA takes place or synthesis of RNA takes place.

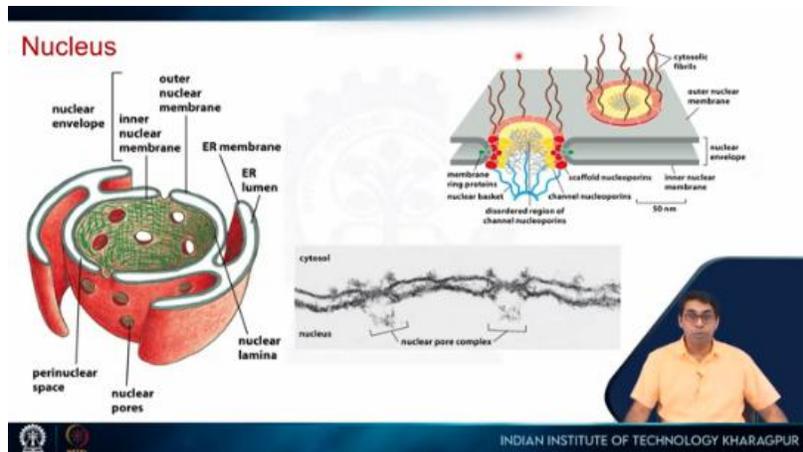
So this is a zoomed in structure of the nucleus. So this is an electron microscope image.



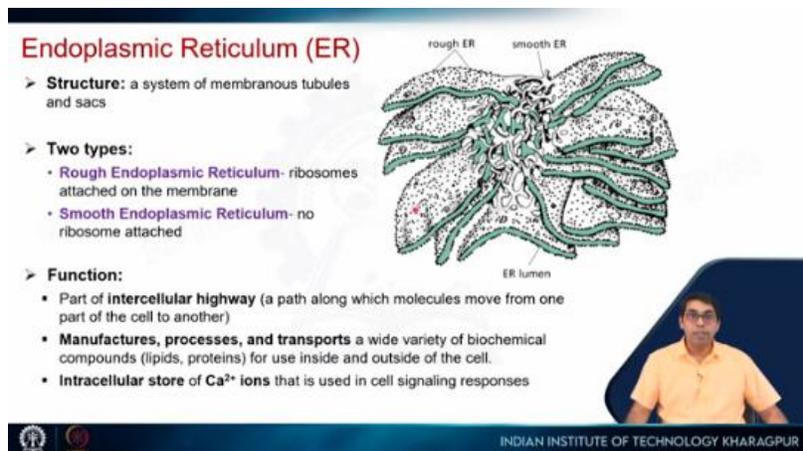
In the next lecture, I will discuss in more detail about this type of image. So if you look at this, there is a nuclear envelope that is present on the nucleus and that looks more like this.



So there is this nuclear envelope and there are pores which are called the nuclear pores. So nuclear pores are these small structures like this which allow passage of molecules through these pores. So there are certain proteins which can pass through this only if they have a signaling sequence. So that signaling sequence will determine whether a protein will remain inside the nucleus or whether it will be transported out or if something is outside whether it will be transported in. Now attached to the nucleus is this endoplasmic reticulum lumens.



So this is the endoplasmic reticulum which is connected to the nucleus and you can see all these dots. These are ribosomes which are embedded on the endoplasmic reticulum. So when this happens, it is called rough endoplasmic reticulum. So ribosomes are attached on the membrane and if there are no ribosomes, it will be called a smooth endoplasmic reticulum. So its function is intracellular. It's an intracellular hybrid. It forms a path along which molecules move from one part of the cell to another part and since you have this ribosome attached, you can imagine that protein synthesis also occurs here.



So again, these are the electron micrograph of the rough ER and the smooth ER.

Rough and smooth ER

A. An electron micrograph showing the **rough ER** in a dog's pancreatic cell that **makes and secretes large amounts of digestive enzymes**. The cytosol is filled with closely packed sheets of ER, studded with **ribosomes**

B. Electron micrograph of a Leydig cell in the human testis that **secretes testosterone (steroid hormone)**, showing abundant **smooth ER**

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Next, after this endoplasmic reticulum, what we have is the golgi apparatus or the golgi complex.

So this golgi complex, they form this stacked flat sac-like structure and what they do is they receive the proteins from the rough ER. They distribute into smaller organelles which get transported out into vesicles. So you can see a vesicle which is budding here. So they get transported out. Now if there are proteins which have to be secreted, they will be secreted out. If there are proteins which have to be delivered to some other organelle, they will be delivered. So processing, packaging and shipping of these molecules are done by the golgi apparatus.

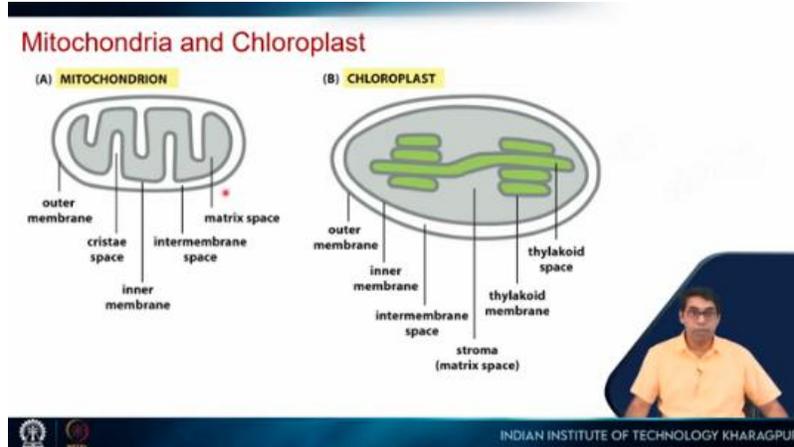
Golgi Apparatus

- Structure: stacked flat sacs
- Function: receives proteins from the rER and distributes them to other organelles or out of the cell (receiving, processing, packaging, and shipping)

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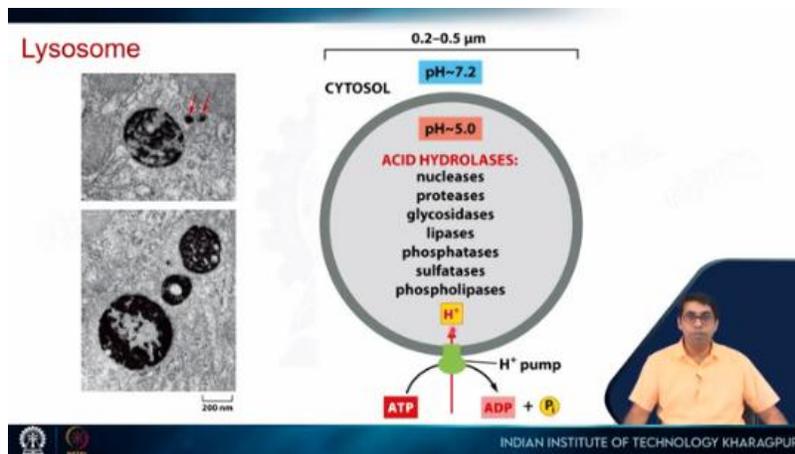
Then there are mitochondria and chloroplasts. So I'm not going to discuss much about this because I will talk about them in more detail when I talk about respiration and photosynthesis.

So these are the energy producing or the powerhouse of the cell. You can also think of them as the kitchen. So this is where energy is produced. I will talk about these organelles in more detail in a week's lecture.



Another type of organelle that is present is called lysosome. So this you can think of as the garbage disposal of the cell. So lysosome, it has a more acidic pH. So, cytosol has a pH of 7.2, lysosome will have a pH of 5 and here, all these macromolecules which have performed their task or they have damaged or they are not required, they will be taken here and they will be shredded into their monomeric components. So, proteins will be degraded into amino acids, nucleic acid will be degraded into nucleotides and they will be recycled so that new DNA or RNA or protein can be synthesized.

We have already talked about it when I discussed membrane protein. We talked about an example of hydrogen pump, where ATP is used to pump in hydrogen and that is why the pH of the lysosome is maintained in an acidic pH which is pH 5.



So for this lecture, you can follow these books, especially Molecular Biology of Cell by Alberts and Molecular Cell Biology by Lodish.

REFERENCES

Following books may be referred to

- Molecular Biology of the Cell (Alberts)
- Molecular Cell Biology (Lodish)
- Lehninger Principles of Biochemistry
- Biochemistry (Lubert Stryer)

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Thank you.