Introduction to Biomolecules
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Lecture – 14
Lipids (Part 3/3) And Introduction to Metabolism (Part 1/2)

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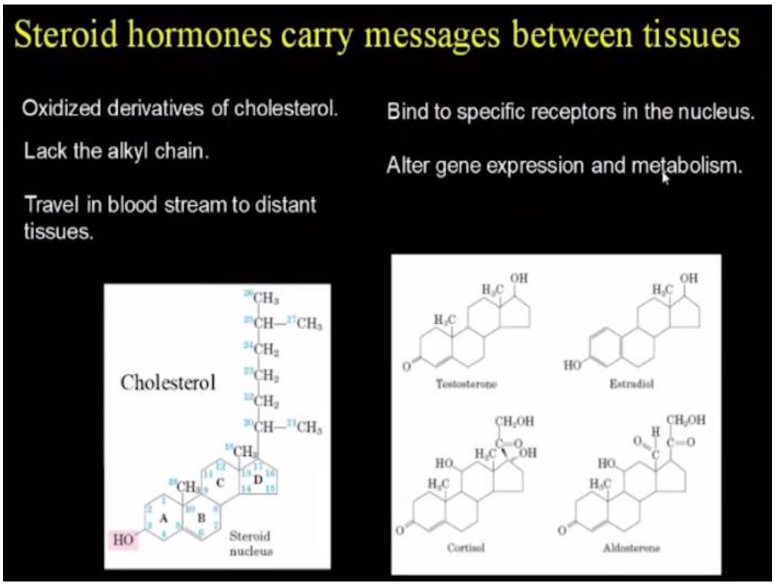

So in the last class, we were discussing about eicosanoids. Like we began the topic on lipids acting as signaling molecules and cofactor pigments, etc. So that is the topic we started and in that first we looked at how the membrane phospholipid that is phosphatidic acid with an inositol where the inositol in the form of trisphosphate IP 3 acting as an intracellular signal like second messenger, so we saw that.

Then we discussed the eicosanoid like the three signaling molecules produced from the 20 carbon fatty acid arachidonic acid like we saw the prostaglandins, then thromboxane and leukotrienes and how they function as signaling molecules. So, we continue that theme today. So today we are going to look at another set of signaling molecules that are lipids. Here the class of lipid is the steroids. These are cholesterol derivative.

So that is why here on the left I have shown you the cholesterol structure, so remember the basic structure of a sterol, this cyclopentanophenanthrene ring. So, this is the basic nucleus of sterols and the derivations like this hydroxyl group, methyl group here, methyl group here and this long aliphatic chain and this is where the individual molecules change and the position of double bonds. So, on the right you have the structures of four hormones.

So, the first one is testosterone. This is the male reproductive hormone. This is produced by the testes and the rest of the male physiology, anatomy, everything comes from the actions of this hormone testosterone. So genetically on the chromosome there is only one gene that determines whether you are going to be a male or not, not the entire Y chromosome and that gene codes for the development of testes that is the only thing.

Then the rest are all the hormonal product of testes which is the testosterone. So without that TDF or testis determining factor located on Y chromosome deleting that but having an entire Y chromosome the default anatomy and physiology everything is actually feminine. So, becoming a female is the default root in development. So, the female secondary sexual characteristics as well as the oocyte maturation, production everything is regulated by estradiol okay.

So, there is only a subtle difference if you look at this, you know this keto enol difference and then this methyl group. So this double bond position is essentially due to this difference, you know this double bond O 2 hydroxyl group and that is why this double bond now becomes between this carbon and this switches to here and then you have one more here because you do not have the methyl group.

So, there is very subtle difference, but it makes profound difference in terms of the signal. So, these are produced by the gonads. This is produced by the testes, this is produced by the ovary. So, there are other sterol hormones, these are produced by adrenal gland. So, the adrenal gland is something that sits on top of the kidneys and these glands have an outer portion called the cortex and then the middle portion called the medulla okay.

So, the cortex produces the sterol hormones, two major kinds called glucocorticoids and mineralocorticoids. Here we have one example each. So, cortisol is a glucocorticoid family sterol. So the name itself tells you glucocorticoid, so the oid is steroid cortic is the cortex of adrenal gland, gluco meaning to do with glucose regulation okay. So, cortisol is important to regulate glucose level.

It promotes glucose formation from non-carbohydrate molecules a process called gluconeogenesis, we will learn later. So, this is important for maintaining glucose level and it is also required for many other metabolic regulations as well as for example regulating immune response. So, this acts as an anti-inflammation. So basically it suppresses immune response.

So you would wonder why one should suppress immune response, immune response is required to fight disease, but you need immune response only when um there is a pathogen okay. So, you do not want a dog that barks all the time, it should bark only when there is a thief around. So, when the immune system does that, when it barks all the time that is what is allergic reaction is okay.

So, a pollen grain that is floating in the air is not going to kill you, but if the immune system thinks that it is a foreign body and overreacts and you get asthma and the doctor earlier like 20-30 years ago used to right away give you a steroid prescription and they act as competitive inhibitors of cortisol and they suppress immune response. But they have side effects, therefore nowadays they do not use it unless otherwise it is absolutely essential.

And the next one is the aldosterone. So, these are called mineralocorticoids meaning they are involved in mineral metabolism. Like for example when the components in the blood are filtered through by our nephrons in the kidney you do not want to lose everything, so there is a reabsorption like for example water gets reabsorbed, sodium, potassium their level in the blood stream is regulated by reabsorption or excretion.

And those mineral levels are regulated by aldosterone and as a result it is very critical for maintaining blood pressure okay. So sodium, potassium levels if they vary beyond the normal range then you have serious problem with blood pressure and heart malfunction, so for that aldosterone is the main regulator okay. So, these are the 4 major steroid hormones that we need to know. So the sex hormones that is testosterone and estradiol.

And then the adrenal hormones, cortisol involved in glucose metabolism and immune response and it is actually anti-inflammatory and aldosterone in maintaining the ionic balance like mineral balance, sodium potassium level maintenance in the blood. So, another important point about these hormones when contrasted with the ones that we recently learned, we did not learn about all hormones we learned about only the eicosanoids.

And that time I told you they function in the vicinity of the cell that produces them and therefore they are called paracrine hormones. By contrast, these 4 are endocrines. So, these are ductless glands and therefore they are called endocrine and but the main point is they act on distant organs by traveling by our bloodstream okay. So, they travel in bloodstream to different tissues, they do not work just in the nearby cells.

And they do not have this long alkyl chain and then since these are hydrophobic, they can directly diffuse through the cell membrane and nuclear membranes and bind to transcription factors like proteins in the nucleus and altered gene expression and as a result finally have an effect on the metabolism.

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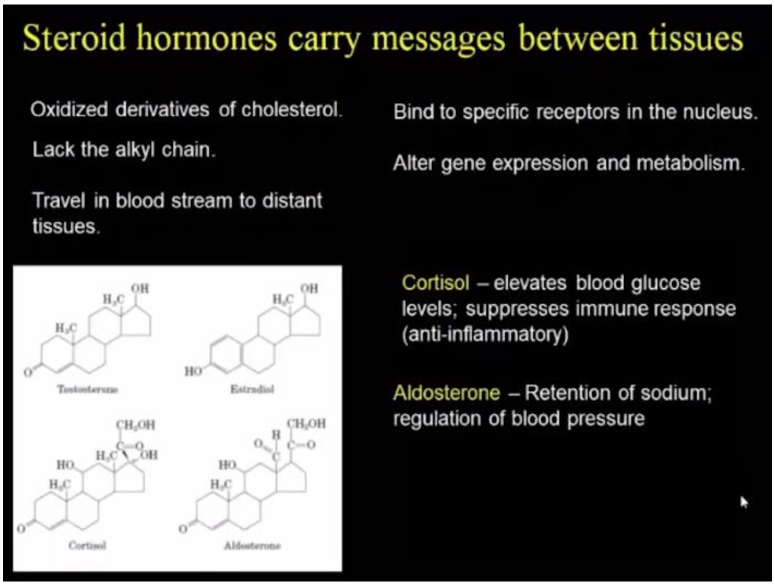

So this is what I just finished telling you without coming to this slide.

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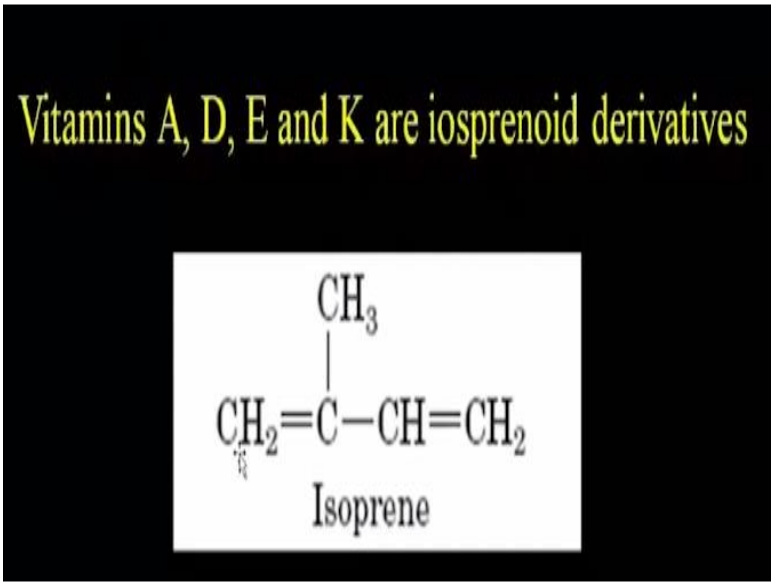

The next group we are going to go to the cofactors. So, we saw the signaling molecules, both the paracrine and endocrine signals. So now we are going to look at the cofactors. So, these cofactors are important for enzymatic catalysis okay. So, they aid enzymes ability to catalyze a reaction by temporarily accepting a group or donating a group. In that manner these cofactors participate in health that is one thing.

So, they are the vitamins and within vitamins you have B complex vitamins that do the job primarily. By contrast, the fat soluble vitamins, the listed over here A, D, E, K; so these are not primarily cofactors in enzymatic catalysis. So they do function along with proteins but not as cofactors okay. So, they help in a variety of cellular processes and we look at them one at a time now. So, all four of them are having this group shown here isoprene, this is 2-methyl butadiene.

So, this is butane if it is fully saturated and you have two double bonds therefore it is butadiene and you have a methyl group at the carbon number two, so therefore it is called you know 2-methyl butadiene okay. And that structure repeats in many molecules and that basic repeat is called isoprene, so isoprene is methyl butadiene. So, this isoprene repeats multiple times in multiple manners.

It is not that always they have the double bond. Sometimes these are saturated as you will see when we look at these four structures and then they have other aromatics rings attached to these repeat units and we will see each one of them as we go.

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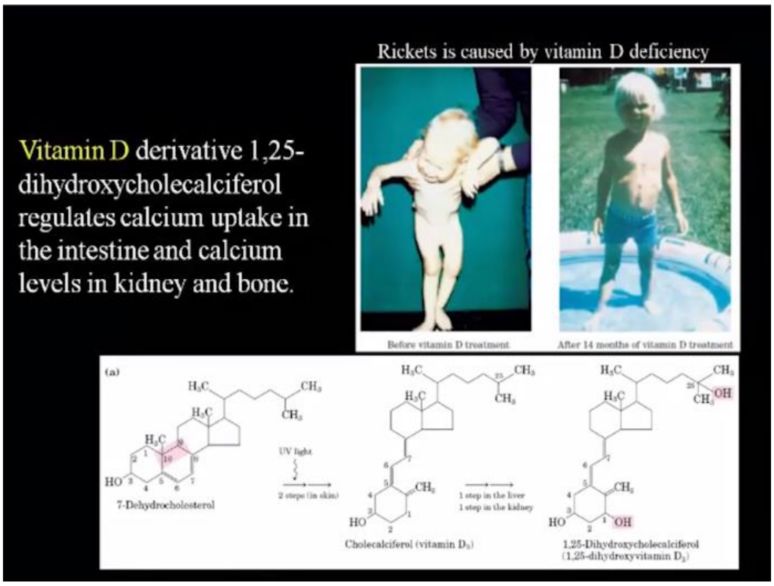

So the first one we are having is D okay. So D vitamin in its active form is shown here on the right 1, 25, carbon 1 here, here 25 th carbon, they have hydroxyl groups. So 1, 25-dihydroxy the basic structure is the cholecalciferol okay. 1, 25-dihydroxycholecalciferol this is what is the active form of vitamin D, also known as vitamin D3 1, 25-dihydroxy vitamin D3. So, this active molecule is produced from this basic structure called 7-dehydrocholesterol.

So this position is the one where the ring opens that is why it is shaded here to create this intermediate, then the hydroxylation leads to the active molecule okay. So**,** this structure upon UV, so this is the reason the doctor tells you to walk in the sunlight at least for half an hour a day, you know we do not normally do it in the modern times in India. So nearly 95% of the Indian population as a result okay, mark my words 95% of the Indian population is deficient in vitamin D okay.

So now it actually has given rise to a debate if 95% are deficient in something do we even need to revisit and understand what is the normal requirement and what is the normal range okay. So that is another debate goes on about the vitamin D, but the main point to remember is the UV wavelengths in the sunlight acting in our skin you generate this intermediate which then through couple of steps one in liver and one in kidney become the active vitamin D and this vitamin by then very name vitamin indicates it is required in the food.

Anytime you say vital, essential what it means is those molecules cannot be made by ourselves they are required for us but they cannot be made and therefore they have to come through the food. So anything that is essential but need to be obtained only through food they are usually called vital or essential, so essential amino acids, essential fatty acids. Wat those two terms mean is those amino acids and fatty acids our cells do not make them, so they have to be obtained through the food.

Simply because ourselves do not make does not mean we do not need them, they are required and that is why they are essential. So here the upper figure is self-explanatory, you know this particular child having vitamin D deficiency. I presume these pictures are from Scandinavian countries because there the sunlight is low and therefore before the discovery of vitamin D's role the children did suffer vitamin D deficiency and they have rickety bones that is why it is called Ricketts disease.

And 14 months later of providing vitamin D you look at how the child is, okay. This is why people say knowledge is power. So, inquiring and investigating nature and understanding the molecular basis of it helped us solve this problem okay. So, this is very traumatic, you can see the difference between these two pictures and this is what vitamin D does. Vitamin D is essential for calcium uptake, calcium homeostasis okay and calcium is an important component of the bone.

So, uptake of calcium in the intestine and maintaining calcium levels, for that vitamin D is essential okay. And this is the isoprene, you might think where is isoprene, in the previous slide you said these are all isoprene derivatives, where is isoprene? So, this three this is what is isoprene derivative. Here we have a bulky steroid nucleus attached to it and therefore you do not see the structure as a big thing. So, this is vitamin D.

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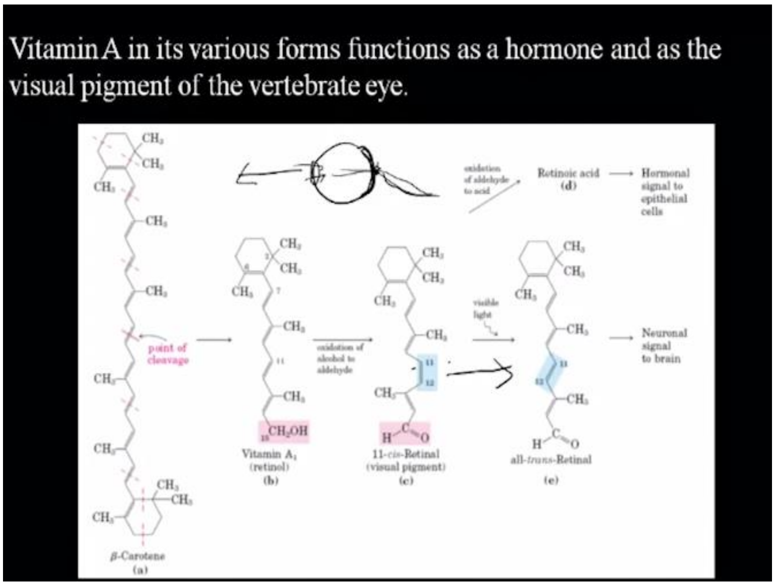

Next is vitamin A. So, vitamin a does couple of things. One it actually functions in acid form retinoic acid as a regulator of gene expression, it is a hormone okay. So as a hormone it signals cells by controlling gene expression okay. It binds to a transcription factor and those transcription factors bind to specific DNA sequences called retinoic acid response elements and activate a gene expression.

And the other major function it does is remember our stereochemistry we learnt about geometric isomerism when you have a carbon-carbon double bond, the groups attached to the two carbons can either have cis orientation or trans orientation. So that is also called cis-trans isomerism. And the cis-trans isomerism in this vitamin A in the aldehyde version okay, so here this is the aldehyde functional group and in this here you have a double bond shaded in blue.

So here you have this group on this side of the carbon and this group on this side of the carbon both are on the same side. So this is 11 th carbon, therefore it is 11-cis retinal. So, this one under the influence of visible light it flips into the trans retinal conformation and this cis retinal to trans retinal conversion upon shining light is how our eye senses light okay. This generates a signal and that through the optic nerve goes to the brain to the visual center and the brain constructs the image.

So, the light is sensed by our eye when the lens focuses eye on the, so I am just momentarily forgetting the name, it converts this retinol cis to trans. So that is how the rods and cones in our eyes the two cells that are involved in sensing light this is the way they sense the light.

This conversion from one isomer to another isomer. Okay the word I forgot is retina. When the lens focuses the light at the back of the eye.

I do not know how much you guys have paid attention in your earlier school or college class like for example I am going to draw here. I will draw by selecting black color. So, let us say if this is your eye ball, so this is as if you are looking this way okay. This is the way you are looking. So this is side way at your eye and if this is where your lens and the light falls here, so at the back of the eye this is what is retina and this is where the light falls and activates.

And this is where this transformation is happening and that through the optic nerve it goes to the brain to visual center and there this basically generates a signal which is electric signal in the optic nerve. So now you understand the importance of lipids in our life okay. So you will be blind without vitamin A and this is trans isomerism, the interconversion between the two. So later once the signaling is over, it reverts back to this.

So, every time this flip flop keeps happening. So in India about 55 million children become blind every year due to lack of adequate vitamin A in our food. And the absence of retinoic acid also leads to growth retardation. So, decades ago a scientist at Johns Hopkins school of public health by observing children in the current Chhattisgarh and Jharkhand area found that lot of growth defects that these children suffer can actually be reversed inexpensively by administering few drops of vitamin A.

Every day for a few weeks and the whole retardation, etc., all are restored. You really do not need to do serious food supplements to make those children to come to normal. So, this is the profound effect of vitamin A. So where do we get vitamin A? Usually from two major sources, one milk, milk directly contains this retinol the alcohol form and then oxidation gives you the aldehyde and then further oxidation of the aldehyde gives you the retinoic acid.

The other really abundant source is a carrot. Carrot color is due to the presence of this beta carotene. It is basically two molecules of vitamin A. So, this double bond needs to be cleaved to make the retinol. So, this beta carotene basically a quarter of carrot per day is enough that those children will not suffer. But unfortunately, you know we have very different priorities and these are not important those children having normal development and not suffering eyesight is not our high priority.

And therefore we do not have to give them this quarter of a carrot per child. So that is philosophical aspect of biochemistry. Let us get back to biochemistry itself. Move on from A to now E.

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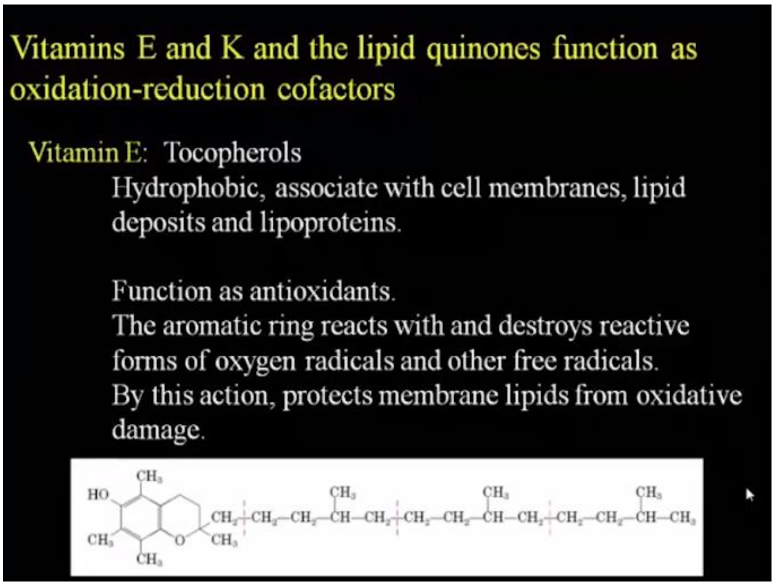

So remember we were talking about rancidity or lipid peroxidation, when you have double bond in the aliphatic chain you can have oxygen to be added between those two carbons and that is the peroxide all that I was talking about on how that causes rancidity and membrane damage all that. So, for that the free radicals that are produced need to be scavenged and they are done by molecules that can readily take up electrons and scavenge electrons and they are called antioxidants.

So, we have two kinds of antioxidants. One that needs to function in the membrane phase and another one in the aqueous phase, in aqueous phase primarily done by a vitamin called vitamin C which is water soluble vitamin. So, we will see vitamin C somewhere else later when we learn metabolism. For now, we focus on the lipid phase. In the lipid phase that antioxidant job is done by these tocopherols, commonly known as vitamin E.

And this is the vitamin E structure, so you have a long isoprenoid unit. So, this indicated by these pink lines and you have this aromatic ring attached to this. So, these tocopherols in the ring structure can easily take up electrons and therefore prevent oxidation of membrane lipids. So, they are hydrophobic, they are in cell membranes and lipid deposits and lipoproteins.

So, these are proteins carry lipids in the bloodstream, we will learn about it when we go to lipid metabolism. So, these tocopherols function primarily as antioxidants okay.

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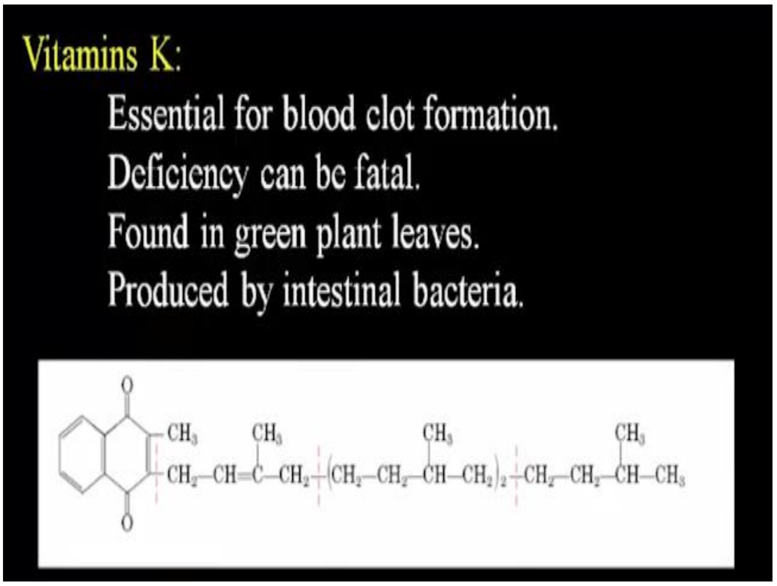

And the last one in this group is vitamin K, also called the dolichols. So, we will see dolichols as a separate group in the next slide. So, these vitamin K are usually found in plant leaves as well as our intestinal microflora, intestinal bacteria produce them. So, if you take a lot of antibiotics usually you have to take some vitamin supplements along with them because the antibiotics that you take to get rid of an infection will kill the intestinal microflora as well.

So, therefore you may suffer some of the vitamin deficiencies including K and K is readily available in green leaves. So, eating green leaves is really important, so essentially eating a lot of vegetables is very important and the less of everything else. And its deficiency can have internal blood hemorrhage okay. So, we have bleeding internally. So, for clot formation you need vitamin K. And here again you have isoprenoid structure you see and with an aromatic ring attached.

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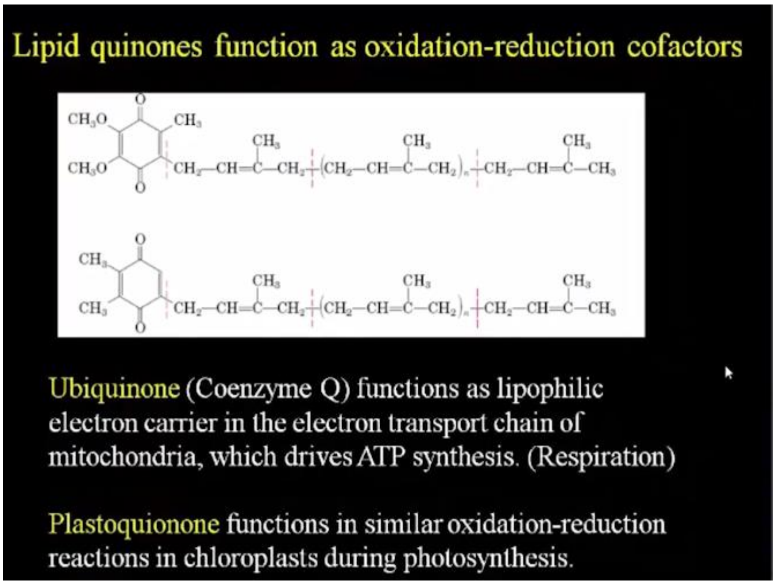

So then remember our title said pigments that are for important and here we see pigments. These functions as cofactors. These are actually important in the electron transport chain in the chloroplast if it is the photosynthesis or if it is the regular respiration in the mitochondria. So, what these molecules do? These quinones because they are the basic quinone structure, so ubiquinone also known as coenzyme Q is on the membrane, so this is in the inner membrane of mitochondria. We will learn this in detail when we go to electron transport chain.

So essentially in this inner membrane you have protein complexes that are embedded on the membrane and these protein complexes transfer electrons from the food that is being oxidized in an incremental step okay. This is like instead of rolling down a slope you are walking down one step at a time okay. To final ultimate acceptor which is oxygen and in the process oxygen gets reduced to carbon dioxide.

So, when these protein more complexes embedded on the membrane transfer electrons in this manner between the two different such complexes on the membrane in the lipid phase this ubiquinone's help in transferring the electrons, so that is what the ubiquinones do. This is in the respiration. And similarly, plastoquinones do the same job in the photosynthesis where electron is obtained by splitting water and that is being transferred and finally to make a reduced form of another cofactor called NADPH.

So, in that process again there are complexes on the membrane in the chloroplast and they are the ones that transfer the electrons and between the complexes on the membrane the lipid phase these plastoquinones help in transferring the electrons and these are the structures. So, these are lipid quinones. These are important for the oxidation reduction reactions. So, since they help in transfer, we call them as cofactors.

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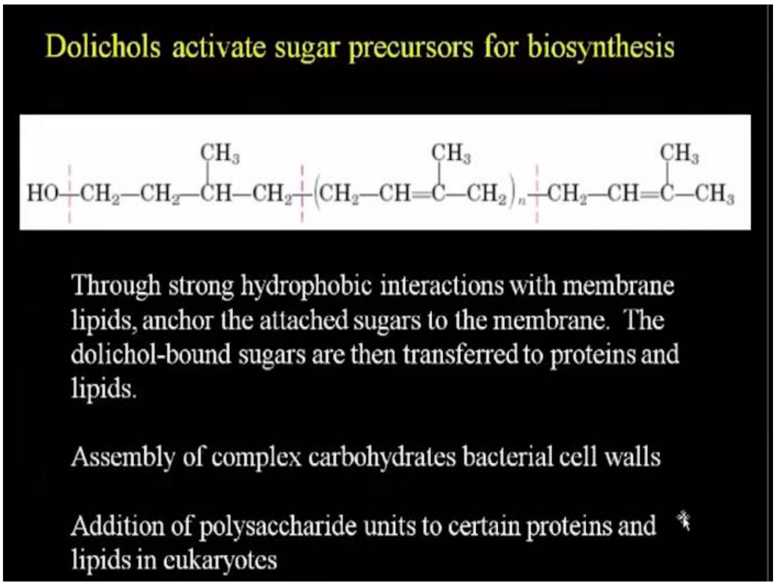

So this is a dolichols. You know the vitamin K is a version of dolichol, just that the dolichol do not have that aromatic group. So, these dolichols are important for activating sugar molecules. For example, the enzymes that are going to add sugars to lipids to make lipopolysaccharides, remember we have already seen them, our blood group is glycosylated membrane lipid like we saw the sphingolipids.

So there we saw the carbohydrates attached and to add sugars like that to the membrane lipids these dolichols help. So, they accept the sugars and then since these are hydrophobic and anchored on the membrane, so they essentially anchor sugars to bring the sugars to the membrane and help in transferring to the membrane attached lipids. And through that process they help the assembly of bacterial cell walls and then they help in adding polysaccharide units to certain proteins as well on the membrane.

So, this is essentially activating sugar precursors for biosynthesis of membrane-bound glycolipids and glycoproteins. So that is what the dolichols do. Alright, with this we finish the second part of our lipid’s discussion. So, the second part primarily focused on signaling kind of lipid molecules. So we saw the eicosanoid, then we saw the steroid hormones, then we saw vitamins D, E, K okay and then the quinones.

So, the first part focused on the main group of lipids like storage lipids like triacylglycerols or membrane lipids like glycerophospholipids and sphingolipids. Then of course steroid cholesterol. So, this is what encompasses the structures and functions of various lipid molecules. So, we have covered at some depth the structure of carbohydrates and then we saw amino acids and therefore proteins, then we have seen lipids.

So, the one group that we are ignoring here are the nucleotides. It is primarily because I am assuming this is being covered in molecular biology, therefore I do not want to duplicate it here so that is why we are not learning the nucleotides. So, we omitting it in this course does not mean those molecules do not belong in biochemistry or not important for a biochemistry to learn, it is to the contrary, they are very much center of the biomolecules.

It is just that in our curriculum it is going to be elaborately covered in molecular biology and therefore I am not duplicating it here. So instead, we will go to what actually all these molecules do? We have multiple times learnt that there are biosynthetic steps break down and build up and enzymes catalyze those reactions, etc. So now we will really get into those reactions.

What are those reactions and what is the logic behind those reactions? And how they are important for the life of an organism? And that whole process is what is metabolism okay, sum total of all interconversions of molecules that happen in our cell.

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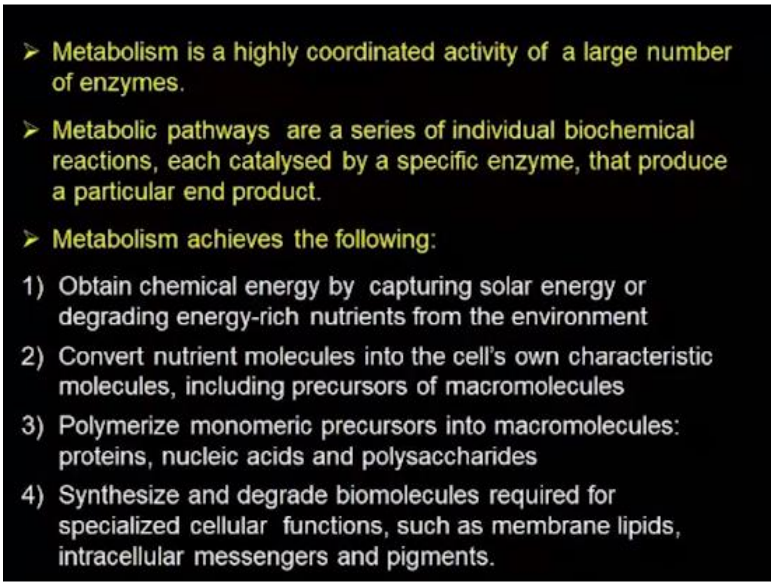

So, we will go step by step. Some students think it is very daunting and very difficult and intimidating all that, but I am hoping that the way we are going to look at metabolism you will end up fascinated and excited about metabolism. So that is what I am hoping. So, let us go step by step to get to that end goal. So once again to recapitulate the definition metabolism is a highly coordinated activity of large number of enzymes okay.

So, because you have large number of steps and they do not act independent of each other they are all coordinated you will readily see in few slides as well as in the rest of the course and in the rest of learning biology in other courses, you will realize that the all the enzyme catalyzed reactions all are highly interconnected and coordinated. And metabolism actually exist in terms of pathways, each biochemical reaction does not happen in isolation.

They are part of a series of individual reactions okay and that series is what you call as pathway. For example, glucose does not become glucose 6-phosphate meaninglessly with glucose 6-phosphate only as the end product. So that one biochemical reaction of glucose getting phosphorylated is part of a pathway that finally produces energy out of glucose okay by breaking down the 6 carbon hexose into 3 carbon pyruvate and in the process partially oxidizing it you get some energy.

And then that pyruvate gets further oxidized ultimately to the most oxidized form of carbon that is carbon dioxide in mitochondria getting some more energy. So, therefore there is an end goal and to get the end goal there are multiple interconnected individual biochemical reactions and those interconnected series of reactions is what is the metabolic pathway. And since they have multiple individual steps therefore you have multiple specific enzymes.

So, what does metabolism achieve? They are listed here. One is energy okay. So either by taking up an energy rich molecule meaning a molecule which has potential for losing electrons and while losing electrons to a molecule that more readily can accept. So, therefore it is delta G being negative and therefore there is free energy release meaning the ground state of the product its energy content is lower than the energy content of the substrate.

So, through that process you get chemical energy. So, this is from the nutrients that is what we do okay. Whatever food we eat, the mitochondria through respiration a process called oxidative phosphorylation and ends up generating energy. Another one what the other organisms you know good examples will be the plants what they do is they use the solar energy to make nutrient rich molecules, so there again they get chemical energy okay.

The solar energy becomes chemical energy. So, these two modes of obtaining energy is one of the goals accomplished by the metabolism. Another one, fine I get some nutrients and the from that do I get only the nutrient energy and nothing else? No, you do make molecules that are unique to your own cells okay. Like for example only adrenal cortex is going to make cortisol and aldosterone okay. So only the rods and cones in our retina require vitamin A.

So, therefore there are cell specific molecules required the building blocks of the individual cells themselves. So, they are also made by rearranging the atoms of the nutrient molecules. So that is another goal of metabolism. The third is building bigger structures okay. Like you provide glucose, then I make a lot of glycogen and store in the liver or I convert even further into fatty acids and convert into triacylglycerol and store in my adipose sites.

Or I make phospholipids and make new membranes and the cells can divide and grow. And then every day my cell is going to divide you have to copy the DNA, so you are making nucleotides to fuse and make long chain nucleotides, so nucleic acids. And you make new proteins and all of these macromolecular synthesis from the monomers is another goal of metabolism.

And the fourth is to make biomolecules with specialized cell function such as the ones listed here lipids, intracellular messengers and pigments and so on. So, these are the 4 main purposes of metabolism okay. Getting energy, cell specific molecule production, then making macromolecules and then producing specialized molecules like the signaling molecules, membrane lipids and so on.

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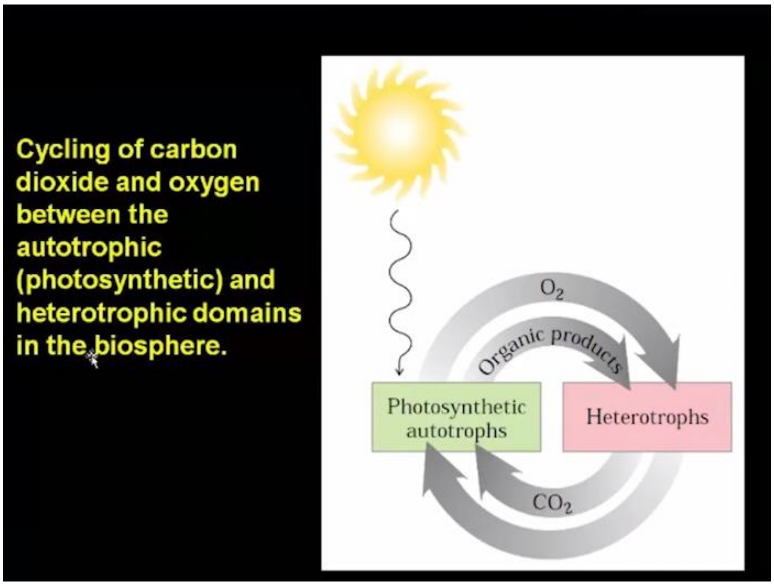

So before we go into those individual reactions, we have to take a bird's eye view of metabolism that is what is going to make us excited about metabolism. We should always have the big picture, and big picture is highly philosophical. You will see that it is simply cycling of matter that is all you achieve regardless of what walks of life you are at or what career goals you pursue.

At the end all organisms existing the only thing they do is endlessly cycle matter in the way diagrammed here and that is unstoppable as long as sun's energy is falling on earth. So, you have these organisms called autotrophs. So autotrophs can make the basic molecules themselves, they do not need energy from the nutrients produced by other organisms. They can use sun's energy and then make energy rich chemicals by themselves and they are called autotrophs okay.

They are not dependent on other organisms for organic macromolecules, they can make from the elements themselves and they are the autotrophs. And the autotrophs that use sun's energy are the photosynthetic like plants, cyanobacteria and so on. And these are going to under the influence of sun's energy convert carbon dioxide and water into major organic molecules that we have learned in the last 13 classes. And why do they make them?

What happens to the molecules that they make? Well, they are eaten by heterotrophs as well as these through their respiration convert them back to carbon dioxide and water. So essentially in the living system like in the biosphere carbon, oxygen and water are massively cycled all the time. Why? There is no answer to that question. This is what happens because sun's light falls and these chemical reactions happen. So, there is nothing more to derive from life than this, it is simply cycling of matter.

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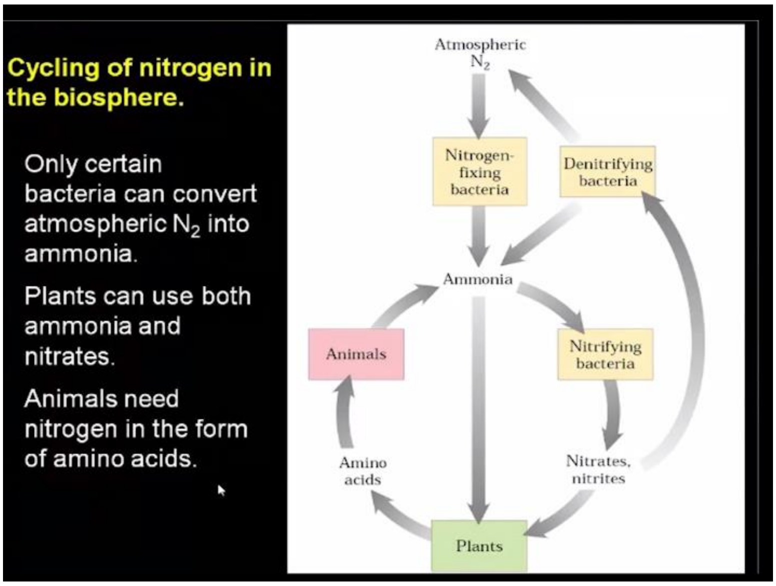

So next a little bit detail on the same thing. So, in the previous one we saw only carbon dioxide and the water and oxygen, so in the process of respiration where you breakdown macromolecules like glucose into carbon dioxide the process consumes oxygen okay. So that is where oxygen comes into picture. And the photosynthesis itself takes up water and in from water is where you get the hydrogen to make these organic products.

For example, you take carbohydrate, you understand carbon comes from carbon dioxide, energy comes from sun. Where this hydrogen come from? That comes from water. So water, carbon dioxide enter into this, then you get organic molecules and then oxygen out of it. And these heterotrophs when they breakdown organic products like glucose back into, I am just using glucose as a convenient example here instead of simply saying organic product.

If you can picture glucose then you will realize glucose is not like fully oxidized carbon. So, in the process of breaking down, they consume oxygen to produce carbon dioxide out of that. So as a result, these molecules like these elements like oxygen, carbon and hydrogen gets cycled in the biosphere. So similar thing happens with the nitrogen as well and that is what is shown in this.

So, our cells cannot readily use nitrogen from the atmosphere although nitrogen is very abundant in the atmosphere that is simply because nitrogen is triple covalent bonded very stable structure. So, you need specialized enzymatic system to reduce molecular nitrogen into ammonia and that is done by an enzyme complex present in a special type of bacteria called nitrogen fixing bacteria.

So, these usually are in the soil usually associated with some plant roots where they are in symbiotic relations with the plants. So, they reduce the atmospheric nitrogen into ammonia and this ammonia can be used by plants by incorporating into amino acids so that is how nitrogen enters into the living system. And from plants in the form of amino acids and nucleotides animals get them. And animals produce ammonia again.

Like this is what is excreted through urine either in the form of urea or uric acid depending on which group of animals you are. And this ammonia again can go into plants against cycling or some of the ammonia in the soil are converted by these nitrifying bacteria into nitrates and nitrites and these are again used by plants the way they can use ammonia. And it does not end there, some of the denitrifying bacteria convert these nitrates and nitrites into atmospheric nitrogen okay.

So nitrifying means getting nitrogen into the biosystem and denitrifying means returning it back to atmosphere that is how you can remember these two. So, otherwise the main thing you need to remember is atmospheric nitrogen becomes ammonia by the bacteria on the root nodules of plants and that is how it enters into the biosystem. So here again you have a massive cycling of nitrogen.

So, we saw the cycling of carbon, hydrogen, oxygen and now nitrogen the four main elements. So, believe it or not much of the diversity that exists in life requires only a handful of elements from the periodic table.

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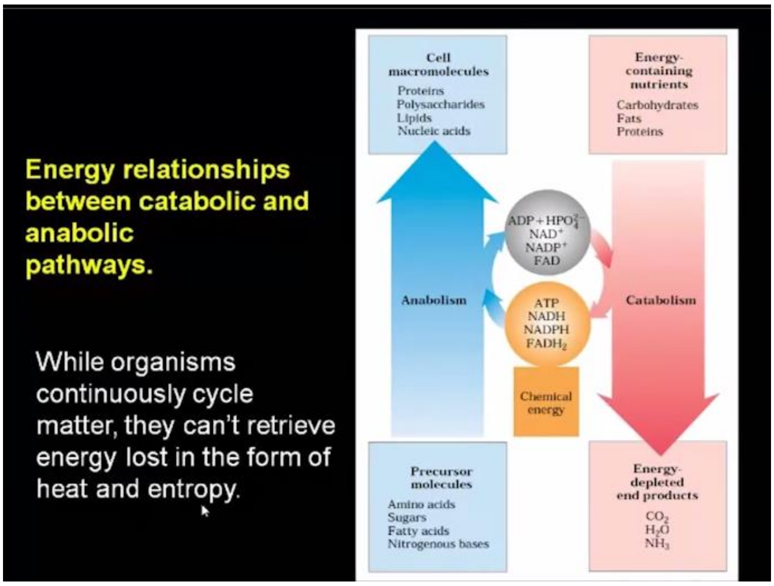

So, the next point we are going to consider before we break today is the energy relationship okay. It looks complex but it is not that difficult. So here we are going to look at two important terms, one is called anabolism, another one is called catabolism. So, these are the two different branches of metabolism. So, the synthetic reactions of the metabolism are called the anabolism and the breakdown steps are reactions of the catabolism.

Like for example breaking down glucose to carbon dioxide and in the process of obtaining energy is a catabolism and taking ammonia, etc., and building amino acids is anabolism okay. So, anabolism is going to require chemical energy and the chemical energy is usually in the form of these molecules, I am not going to get into the details because we are going to look at each one of them their structure and function later when we get into metabolism details.

So, these are the molecules, these are highly reduced and their oxidation gives you the energy required to drive the anabolic reactions. And so here you have the precursor molecules getting converted into macromolecules so that is anabolism. And then you can see from the products why this is important, right. You need to make proteins, polysaccharides, lipids and nucleic acids, etc., for normal cellular function from the precursors.

So, these usually come from the food. Now when these are being broken down by for example the glucose breakdown in mitochondria, then these molecules are reduced and that is how the chemical energy from this are transferred and temporarily stored here and then you have energy depleted molecules into the atmosphere okay. So, these are the steps or the two different major groups, one set called anabolism, another set called the catabolism.

So, the main point is in this bullet here. So while this appears like a cycle, it is not perfect like a certain quantum of energy that is required for this anabolism, a specific anabolic reaction is not fully realized when that particular macromolecule in the reverse reaction is converted into energy depleted end product. So essentially you need more than what you produce in the opposite direction and the difference is lost into the environment in the form of heat and increasing the overall entropy okay.

That is how living system obeys the loss of thermodynamics, particularly in this case we are talking about the second law of thermodynamics, the entropy keeps increasing. So, energy flows continuously from the sun and it is not perfectly used in this cycling, instead some energy leaves from the biosphere into the universe. So essentially this is unidirectional flow of energy. So organisms cannot retrieve energy lost in the form of heat and entropy.

So, with this I will stop here and tomorrow we will continue into other aspects of metabolism like the main characteristics of metabolism, still overall views. And then we will get into some important basic chemistry concepts required for understanding metabolism. So that is what we will do it in the next class.