

Science and Technology of Polymers
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Lecture - 13
Structure and Properties of Polymers (Contd.)

Good morning, last class we discussed about the molecular weight and its distribution of polymers, and I showed that an order of weight average molecular weight greater than number average molecular weight greater than number average molecular weight which shows a polydispersity in a polymer sample. And the ratio of the \bar{M}_w over \bar{M}_n keeps the polydispersity index, and values of polydispersity index beyond one indicates a broad distribution. Depending on the polydispersity value one can select a suitable polymer sample or sample for production of different goods.

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Typical Molecular Weight Determination Methods			
Method	Type of mol. wt. Average	Applicable wt. Range	Other information
Light scattering	\bar{M}_w	To ∞	Can also give shape
Membrane Osmometry	\bar{M}_n	2×10^4 to 2×10^6	--
Vapor phase osmometry	\bar{M}_n	To 40,000	--
Electron and X-ray microscopy	$\bar{M}_{n,w,z}$	10^3 to ∞	Shape, distribution
Isopiestic method (isothermal distillation)	\bar{M}_n	To 20,000	--
Ebulliometry	\bar{M}_n	To 40,000	--
Cryoscopy	\bar{M}_n	To 50,000	--

Now, there are various techniques as I mentioned for measuring the molecular weights or determination of molecular weights. Now, here is a table it shows the different techniques like light scattering membrane osmometry, vapor phase osmometry, electron and x ray microscopy, isopiestic method that means isothermal distillation, ebulliometry boiling point animation, cryoscopy freezing point depression. So, and the range of molecular weights which are sensitive to each of these different molecular weight techniques are shown over here. So, from this you can select. So, for very high molecular

weight say ebulliometry cannot be suitable, whereas for a low molecular weight membrane osmometry can be suitable.

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Method	Average	Range
End-group analysis	\bar{M}_n	To 20,000
Osmodialysis	\bar{M}_n	500-25,000
Centrifugation		
Sedimentation equilibrium	\bar{M}_z	To ∞
Archibald modification	$\bar{M}_{z,w}$	To ∞
Trautman's method	\bar{M}_w	To ∞
Sedimentation velocity	Gives a real M only for monodisperse system	To ∞

Others are also end group analysis. End group analysis means there may be some polymer samples, polymer molecules whose end groups contain certain functional groups. Say in case of condensation chain polymers there may be function groups like amine, halogens, carboxyl group, hydroxyl groups so those end groups could be analyzed and by analyzing the end groups one can calculate the molecular weight. Details of end group analysis can be available in the book of Professor P Ghose.

In case of addition chain polymers at end group analysis methods can also be applicable provided initiators are functionalized. So, initiator fragment remains attached to end of a polymer chain. So, by counting the end group one can calculate the molecular weight by end group analysis. So, this way various are the techniques are also available. This is for your information only if you need in future for determination of molecular weight you can go with any of these techniques.

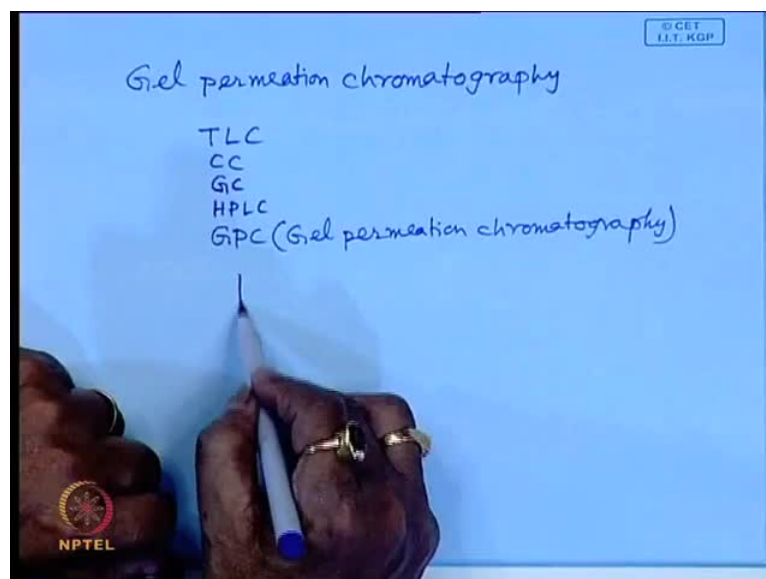
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Typical Molecular Weight Determination Methods* (Contd..)			
Method	Type of mol. wt. Average	Applicable wt. Range	Other information
Chromatography	Calibrated	To ∞	Mol. Wt. distribution
SAXS	\bar{M}_w		
Mass spectroscopy	M_n	To 10^6	
Viscometry	Calibrated	To ∞	
Coupled chromatography-LS		To ∞	Mol. Wt. distribution, shape, \bar{M}_w \bar{M}_n

 "To ∞ " means that the molecular weight of the largest particle soluble in a suitable solvent can be determined in theory

And chromatography is a very good technique for molecular weight determination. Although, it is a secondary method, it needs a calibration standard based on which you can get the distribution curve; from that distribution curve you can get the molecular weight also. What is chromatography?

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Now, there is a technique known as gel permeation chromatography. You know what is chromatography? Chromatography is a separation technique from a mixture. If there are more than one components in a mixture those components can be separated by

chromatography. There are various techniques in chromatography thin layer chromatography, column chromatography, high pressure liquid chromatography. So, TLC column chromatography, gas chromatography, high pressure liquid chromatography and GPC. GPC is gel permeation chromatography.

Basically, in this, in all these techniques a stationary phase is used which is highly active. That stationary phase when comes in contact with the mobile phase containing the components in a mixture to be separated then (()) there are some interaction occurs between the stationary phase, phase and the components in the mobile phase. And those components in the mobile phase which are to be separated gets absorbed or interacted or hold by this stationary phase, this way a separation can be affected.

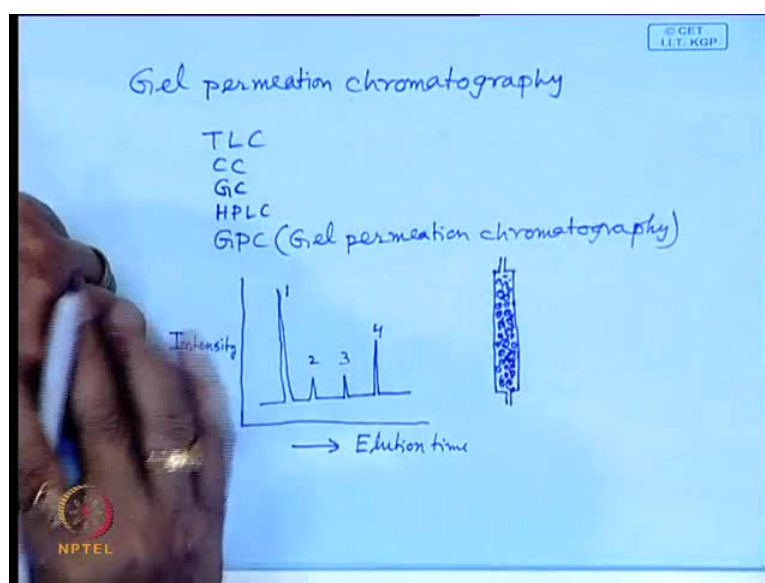
If you think of column chromatography, column chromatography is a very simple technique. You have to take a long column vertical column which should be packed by a stationary phase say sephadex which are something say silica or aluminum particles or I do not know exactly say the composition of sephadex, but it contains some stationary phase. So, that stationary phase is used for packing the column with the help of water which is used as mobile phase their or sometimes organic water mixer can also be used after packing.

Then this or from the top of the column some, a small quantity of solution is added poured on to it then gradually, continuously some solvent that may be a mixture one or two solvents or a pure solvent that should be continuously added at the top and from the bottom with the help of a stop cock, this goes down. While it passes through the column phase it gets separated and at the bottom of this a column if it is connected to some detector, so the detector can help how many components are passing through the column at what time, that is called elution time.

So, this is the basic principle of column chromatography. That basic principle of column chromatography has been extended to high pressure liquid chromatography because column chromatography technique is a time consuming process. For separation of one mixture it may take few days whereas the same can be done within a hour or even less within a half an hour time or may less than half an hour time, it in a high pressure liquid chromatography. Basically, a high pressure liquid chromatography instrument contains a column, short column like this.

Its length might be say 1 feet or something like that and it is connected to a high pressure pump through connected with a injection port. So, in that injections port this sample injected and that pump pump take the solvent from the reservoir and pumps to the injection port to the column. So, this way it carries the mixture through the column and column contains a packed bate and while it passes through the column depending on the partition coefficient of the component between the mobile phase and the stationary phase separation occurs. And from the other side of the column it comes out which is connected to a detector it may be refractive index detector or eve detector. That helps to know the separation.

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And it gives a picture like this say if there are more than one component it may look like this. So, each component specified for once, each peak specifies for a one component say component 1, component 2, component 3, component 4. This is the elution time and this actually say intensity of the detector. So, this component 1 it gives a peak like this, this indicates, this is proportional to the concentration and this is the elution time of the component 1, elution time of the component 2, elution time of the component 3, component 4 like this.

So, this way shows that it is separated. Now, it cannot tell you exactly the identity of the component 1, 2, 3, 4 here. It just separates and indicates that the components in a mixture are separated. In order to know that you have to collect the component or the solute

present in this fraction. Then you have to correct measure to isolate and then purify or as well as you have to take the solid things, then you have to go for spectroscopy analysis IR, NMR etcetera. From that you can know what is the, what is the identity of the fourth component.

So, there are various details are available in your book, you can go through that. Now, this concept has been extended to gel permeation chromatography. Basically, a gel permeation chromatography instrument contains a column which is packed with say porous beads of small particles size. That porous beads contains, porous beads are made of cross linked polystyrene. So, cross linked polystyrene beads are used as a packing material in gel permeation chromatography.

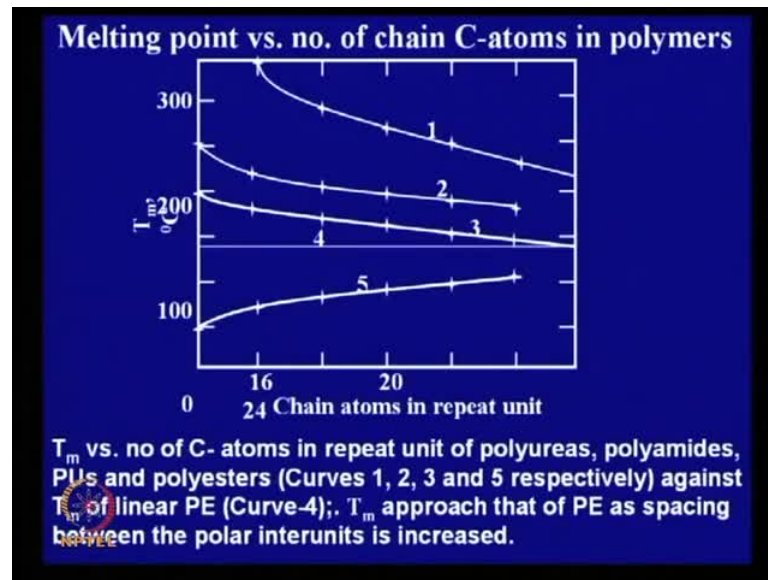
Basically, there is no difference between the principle of, principle, difference of principle between the GPC and HPLC. Only the column packing material GPC contains packing with spherical beads. Since, it is porous what happens if you inject a polymer solution of dilute concentration, small concentration, what happens? It enters the column. On entering the column small molecules, smaller molecules can enter into the porosity of the beads, porous pore volume of the beads, porous pore of the beads while bigger molecules can penetrate within the bead, but it passes through the inter particles space like this, it moves this way.

So, depending on the size of the polymer molecules few will enter into porous beads at faster rate, medium size will, can enter into the porous beads at a lower rates whereas biggest molecules would not penetrate at all to the porous beads. So, while it comes through the other side of the column then it is a separated one that means fractionated one that passes through a detector that detects that it contains so many different fractions fraction 1, fraction 2, fraction 3, fraction 4, fraction 4, 5 like this.

Now, if you have a calibration standards say you have to take one polymer of standard molecular weight, known standard molecular weight. First, you have to run that your GPC with the standard molecule, standard polymer of known molecular weight plot a calibration curve, you will get a calibration curve. Based on that calibration curve you can know the distribution nature of your test polymer solution of which you want to measure the molecular weight.

So, this is the basic thing what is done in gel permeation chromatography. In fact most of the polymer, molecular weights of majority of the polymers are verified or known or measured by this GPC because all the time this absolute molecular determination techniques may not be accessible to each and every body.

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Now, let us pass on to other part of the structure property co relations of polymer materials. Structure I mean you have to consider that a polymer molecule, it has a chemical structure. Say you think of a polyester, its chemical structure is known, polyethylene its chemical structure is known, polypropylene its structure is known. So, chemical nature as well as its configuration these are known from the theory. Then you learnt to predict the properties of a polymer sample. How this structure and configuration of polymer molecule helps.

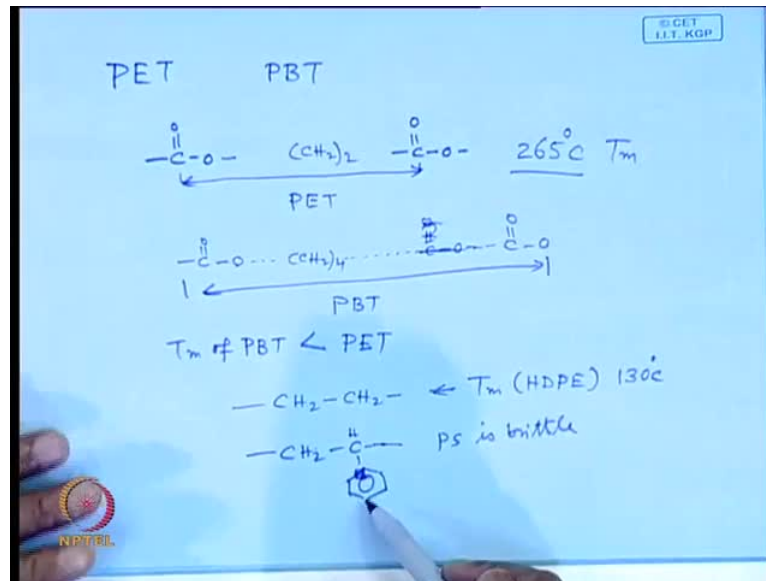
Not only that you have seen that with the increase in molecular weight of polymers their properties changes sometimes it, the properties level increases or with the decrease in molecular size property decreases. Not only that with the extent of branching with the extent of linearity with the extent of non-linearity with the extent of cross linking say cross linking, less cross linking intensity low cross intensity polymer, high cross intensity polymer there is a variation in properties. So, we have to know and there is also variation in morphology of the structure and morphology of the polymers.

Now, this diagram shows interestingly say this is temperature axis, melting temperature of polymers in degree Celsius and actually there is a problem in the figure this is 20, this is 24, read it, a setting of this thing 0, 16, 20, 24. Now, there are four 1, 2, 3, 4, 5 curves. This also a curve, it is a horizontal one. This is also a curve, this curve 4 this shows the T_m melting temperature of linear polyethylene. What is the x axis it is the chain atoms in repeat unit that means number of carbon atoms per repeat unit, try to understand.

You think of a polymer molecule. Here the information is shows like this, in the polymer molecule what are the number of carbon atoms in per repeat unit. Based on the carbon atoms for repeat unit there melting temperatures varies, changes. Now, if you think of polyethylene, think of polyethylene there is no change in melting temperature with increase or decrease of number of carbon atoms whereas in case of carbon, which actually correspond to polyureas, curve 2 correspond to polyamides, nylons, curve 3 correspond to polyurethane and curve 5 correspond to polyesters.

So, this is polyurea, this is polyamide, this is polyurethane, this is polyester. Say PET. Now, you see in this case with the increasing number of carbon atom in the repeat unit there melting transition decreases and approaches that of polyethylene. So, is the case with polyurethane. So, is the case with polyester. In this case, in case of polyester it also approaches that of polyethylene. That means this spacing between the repeat, your functional groups if there is a change in spacing between the functional groups then there melting temperature is affected.

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I give you a simple example say you consider this PET and PBT. What is PET? Polyethylene terephthalate that means glycol ethylene, there are two carbon atoms in the glycol, but polybutylene terephthalate there are four carbon atoms in the glycol part. So, there is a difference of two carbon atoms from PET to PBT. Obviously, the distance between two ester groups here say suppose this is case of PET, this is the distance in between there is C H_2 whole 2 and in case of PBT C H_2 whole 4.

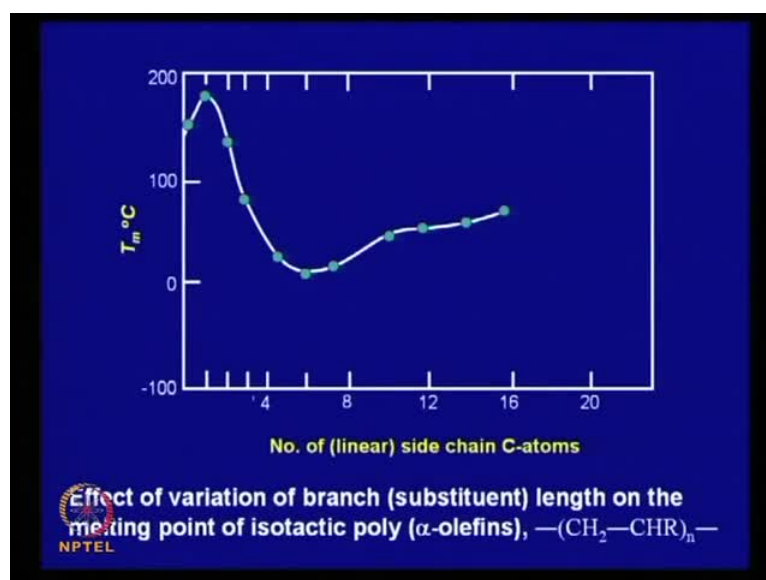
So, obviously the distance between these two carboxyl's, I should have drawn little this side. So, this length is longer than this length. So, obviously the melting temperature of PBT will be what? Because methylene group this carbon chain, carbon carbon bond can rotate and it is flexible, it is highly interesting. Similarly, polyethylene, simply polyethylene there is also it is flexible, but and this flexibility is related to its glass transition, I discussed what is glass transition, later.

So, polyethylene is flexible and, but but its flexibility is little restricted due to closer packing of the linear chain molecules because of this size of the hydrogen's attached to carbon. Now, you think of a polymer where one of the hydrogen in ethylene unit is replaced by say sorry a phenylene, it becomes polystyrene, flexibility is lost. So, replacing one hydrogen in ethylene by one phenylene, its flexibility is lost. Here you have seen the chain contains methylene group as well as one phenylene in polyester.

If you compare this polyethylene and this polyester what happens? The melting point of this polyester PET is around 265 degree Celsius T_m of this polymer whereas T_m of this polymer is say if it is HDPE; it is around 130 degree Celsius. Look at the difference between these two, why so? It contains carbon chain, carbon carbon bond, it also contains carbon carbon carbon bond. In addition to this carbon carbon bond it contains one carbon oxygen bond as well as in this molecule there is one phenylene in the backbone itself. Now, that phenylene in each repeat unit restricts its mobility.

So, this becomes rigid at a min condition as compared to this one. Although, this is rigid because of this your smaller size, but there are other polymers which is not that rigid. Again, if you compare this polymer with this polymer it is rigid as well as it is brittle. It is a brittle polymer. This polystyrene is a brittle polymer whereas polyethylene is a tough and strong polymer. It can absorb impact energy whereas polystyrene cannot. So, these things should be understood or known by critical examination of the repeat unit formula and the repeat unit configuration. It is not very difficult, provided you know the molecular formula of the repeat unit, provided you know the bonding nature between the atoms in one repeat unit.

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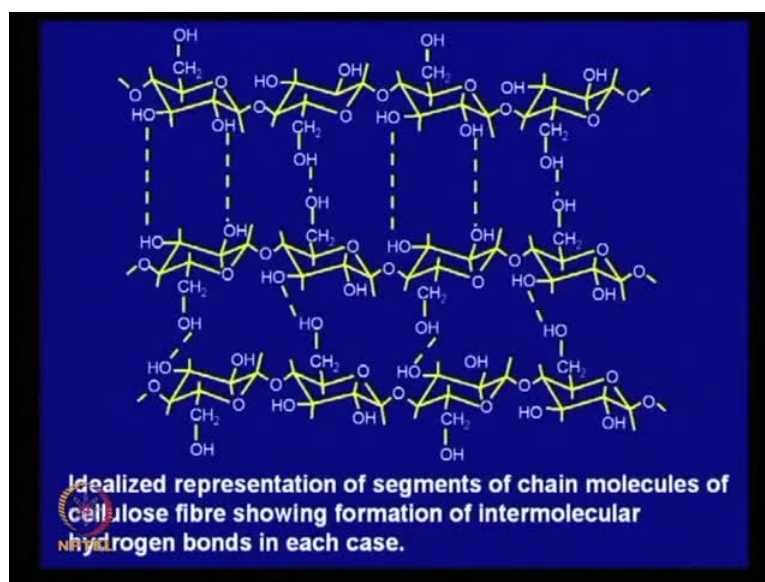
Here is another representation. You see melting temperature of polymers are related to number of side chain carbon atoms. Well, if we consider that the melting temperature can vary depending on the number of carbon atoms per repeat unit between two polar

functional groups. But what can happen, if there is a branch structure or a branch short or a long branch attached to a back bone chain and that too what are the number of carbon atoms present in that branch chain.

You see here the melting temperature first increases if the number of carbons are less. Then with the increase in number of carbons in the branch that means for long branch, long length of branch structure the melting temperature decreases further it shows an increasing trend, why? After pursuing through certain length of the branch, if it goes beyond that what happens? It becomes like a linear molecule. That means it can arrange the alignment with the main back bone chain. So, for, so it shows increasing trend of melting temperature beyond certain number. So, these are the things we will find.

That means if you want to correlate the properties say thermal properties, mechanical properties, solubility properties and other properties you want to find out the reason why it is so? Then you have to look into the structure of the polymer. If it is an unknown polymer then you have to evaluate the chemical structure of the polymer, then you have to correlate the properties.

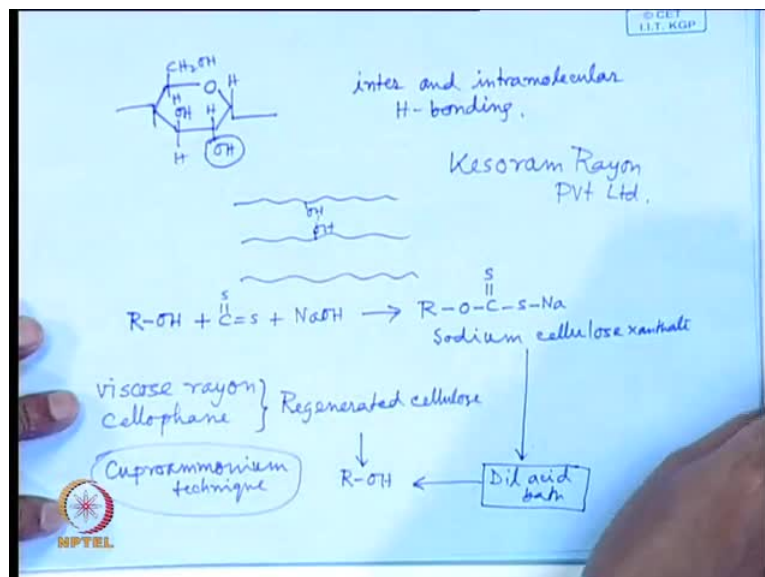
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Look at this structure. These structures are available in the book. What is this structure? It shows the formula, chemical formula representation of a cellulose molecule which basically shows a repeated union of anhydrous glucose units, these are actually anhydrous glucose units. It contains both primary and secondary hydroxyl groups.

Primary and secondary hydroxyl groups, you can see in other way also. This may be little complicated to students from non chemistry background, just you see.

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You can visualize in this fashion also. This is primary hydroxyl groups, this is, these are secondary hydroxyl groups present in cellulose and hydro glycogen ring. Now, these hydroxyl groups enter into extensive hydrogen bonding inter as well as intra molecular hydrogen bonding. What happens then? I told you cellulose is a thermo plastic polymer, but it behaves like thermo set polymer because we do not find any solvent for cellulose. We cannot melt cellulose, if you heat cellulose it will not melt rather it decomposes.

Why so? Because we know a thermo plastic polymer, if we put a thermo plastic polymer in a solvent it goes in dissolution. If we heat it it softens and melts, but cellulose although it is thermo plastic polymer it does not because it contains extensive inter as well as intra molecular hydrogen bonding. What are those things? Suppose, it contains O H, here also it contains O H. So, these O and H can enter into hydrogen bonding. So, there may be many because a look into this units, each and every unit can enter into hydrogen bonding with other polymers.

So, total amount of hydrogen bonding, (()) per gram of polymer is huge. So, it does not go into solution, but it can be converted into solution provided you carry out some chemical treatment. What is that? Suppose, if we represent this cellulose as R O H. Cellulose is basically an alcohol, chemically an alcohol. So, if we represent a cellulose as

ROH in order to make it soluble you add carbon disulphide along with sodium hydroxide. What happens? It forms sodium cellulose xanthate. This is highly soluble in water. Now, we have read viscose rayon cellophane etcetera these are nothing but regenerated cellulose. How it is done, how this regeneration is done, what is that viscose process, what we will do? You take sodium hydroxide solution, alkali solution, into that alkali solution we put cotton then we add slowly sodium hydroxyl sorry carbon disulphide $C S_2$.

So, that is highly reactive and forms this kind of compound, then when it is put into an acid bath say dilute sulfuric acid, what happens? You get the cellulose back. This is regenerated cellulose, mercerized cotton, processed cotton today; we are using this processed cotton as our garments. This process cottons are soft whereas raw cotton is very rough, roughness of raw cotton is decreased by this viscose process, mercerization process.

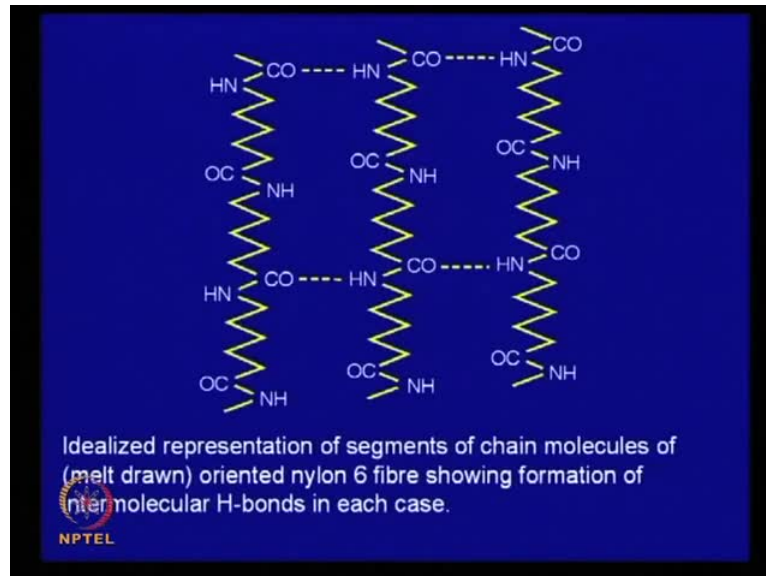
Cellophane is nothing but regenerated cellulose film. How this cellophane is made? Jewelleries and many other products are obtained from wood pulp. There is an industry in Bengal, they are making in huge quantity this rayon and other regenerated cellulose set up from wood pulp. You will be surprised to see. So, cellulose is extracted from there by pulping assorted by pulping then it is interacted with carbon disulfide. There are various other techniques say cuproammonium technique other than this viscose process is also available. So, if you are interested you can go through here.

Now, what I wanted to say with this representation there is a extensive hydrogen bonding. What happens here in this reaction? Actually, this breaks this hydrogen bonds. Once, it break the hydrogen bond then this cellulose go into solution then when it is passed through acid bath the cellulose is regenerated. Once, cellulose is regenerated what happens? It cannot reform the same number of hydrogen bonds as it was present originally and by virtue of this large number of hydrogen bonds present in this molecule, intra molecular hydrogen bonds, if these cellulose is crystalline only crystalline polymer.

Now, its cristanality is reduced by this viscose process, mercerization process, you can verify it. You take the x or d of raw cotton then you take the extra diffraction of this mercerized cotton, you will find that its cristanality is reduced that is due to decrease in hydrogen bond also you can verify this with the help of Fourier transform infrared

spectroscopy. There you will find that hydrogen bond has been decreased, extent of or concentration of hydrogen bonding has been decreased after this viscose treatment.

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Here is a, another example of a polymer say polyamide, nylons or polypeptides. In polyamides helical structure in polypeptides in proteins, there structure is only depended on this hydrogen bonding as well as cross linking. Their cross linking atom might be sulfur and or other things, other atoms in proteins. In polyamides the strength of polyamide depended on the high polar polar interaction arising out of this interaction between oxygen and nitrogen present in separate different molecules, so these this also forms in the strong intra molecular hydrogen bonds. So, this intra molecular hydrogen bonds actually controls its solubility in a solvent control its melting temperature.

Now, at this point I should mention that this polyesters and polyamides are manufactured or synthesized in melt condensation process not through solution process, it is not possible. Of course, there is a technique known as inter facial polymerization technique which can be utilized for synthesizes of nylon like polymers other than melt poly condensation and this melt poly condensation what happens?

Once, this molecules grow in size then there viscosity gets very high and it melts at higher and higher temperature that is why you have to maintain a very high temperature say from 260 to 280 or 90 degree Celsius temperature in the reactor so that it remains fluid and you can get high molecular weight nylons. So, here you see also the effect of

hydrogen bonding on the molecular, on the polymer properties, there melting temperature.

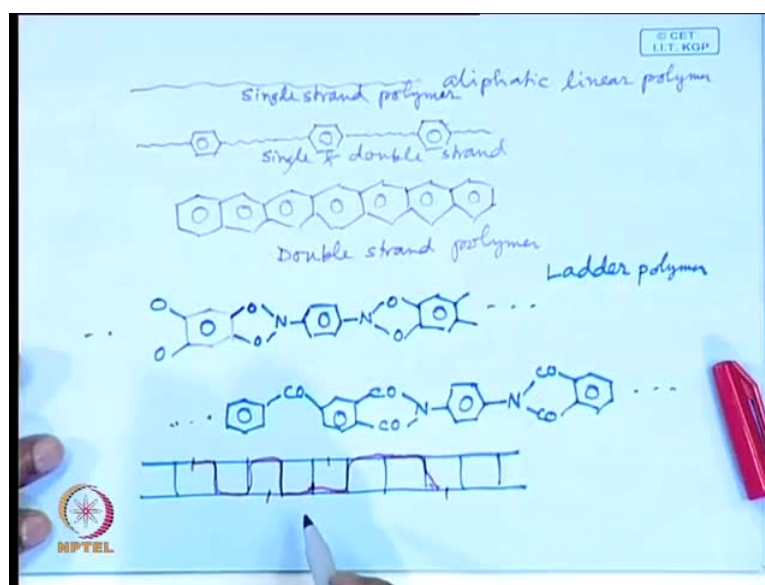
The melting temperature is not all, it is hydrogen bonding make them crystalline, make these polymers stiff, make this polymer strong. Now, this nylon is so strong provided the length between to polar and function groups, amide groups length between amide groups if that is regulated then one can get very tough and strong polymer which is used for making mechanical gears. Mechanical gears are made of this nylon self lubricating gears. Self lubricating gears are made from these polyamides.

Today, sometime self lubricating gears are also made from ultra high molecular weight polythene. Now, here you understand where from this strength comes, where from this toughness comes? In case you just compare this nylon ultra high molecular weight polythene poly carbonate and aromatic polyamides, polyether ketones, polysulfones, these are engineering polymers polysulfones, polyether ketones. Please note down, engineering polymers, polyether ketones, polysulfones, aromatic polyamides, poly carbonates.

These polymers are known as engineering polymers and these polymers can withstand higher temperature or their service temperatures can be very high as well as they can bear huge mechanical load without breaking. That means this polymers are also mechanically tough, not only that the dynamic properties, dynamic properties I mean device exposed to dynamic stressing or dynamic loading does not fail. That means it can absorb this cyclic stress energy without fail.

So, this diagram, this picture shows an indication how that is done. Now, here you see if it is made of aliphatic chain, if the units present between two polar units a aliphatic chain what happens? Aliphatic chain is flexible. So, you can get flexible structure. Now, if you want to have a rigid structure then you can place one phenadrine here, you can have a polymer exclusively made of aliphatic chains along with the back bone aliphatic units or you can have exclusively aliphatic units or you can have a mixture. That means you have the (()) option you can design a polymer, you can synthesize a polymer having both aliphatic as well as aromatic units in one back bone chain as you like you can make.

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So, this indicates a concept say you are having a polymer chain exclusively linear made of aliphatic, aliphatic linear polymer. Now, along with this aliphatic units if you have some aromatic rings placed after some intervals in the length then there properties changes flexibility that means this is mechanically stronger than this polymer, this is, this polymer is thermally more stable than this polymer. So, what you have got? Improved mechanical properties or higher mechanical properties, higher thermal properties, but at the same time if you move like this you can achieve a polymer with hybridness. So, you have to think of the impact properties also, you have to keep in mind the impact characteristics also.

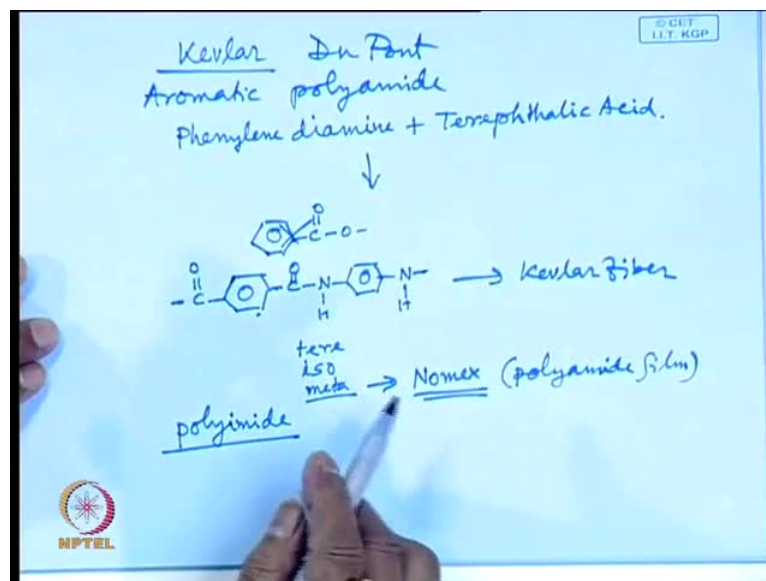
We need a strong polymer as well as high impact polymer as well as thermally stable polymer as well as we must see that it becomes easily processable that means you have to think of the processability temperature at which it melts, not only that if you go for solution processing you have to find a suitable solvent so that the polymer, this polymer goes into solution easily. But as you move from the linear structure to this kind of structure continuing phenadrine then you have to compromise with solubility, you have to compromise with the mechanical properties etcetera. This way you have to optimize if you want to tailor the structure.

Now, what happens? This way we can just lead to a structure like this. This is a single strand polymer. This is a combination of single and double strand polymer. This is a

double strand polymer. You can have polymer like like this. You can have polymer like this so on. What are the characteristics of such polymers? This is soft flexible, this is rigid polymer, rigidity is increased. This far rigid polymer, again rigidity and thermal stability they are compromised where these polymers are known as multi strand polymer or double strand polymer are known as ladder structure, ladder polymer.

This looks like a ladder, looks like a ladder, ladder polymer. They are thermally stable. Why? If there is some agency which can break this point, is going to break this point, still polymer remains stable. The polymer is not disintegrated because the polymer chain integrity is showed to this, like this, the polymer structure is now totally destroyed. So, this is a thermally stable polymer, but at the cost of solubility, at the cost of processability, these polymers are difficult to process. One example, I give you that is kevlar used for making bullet proof jacket.

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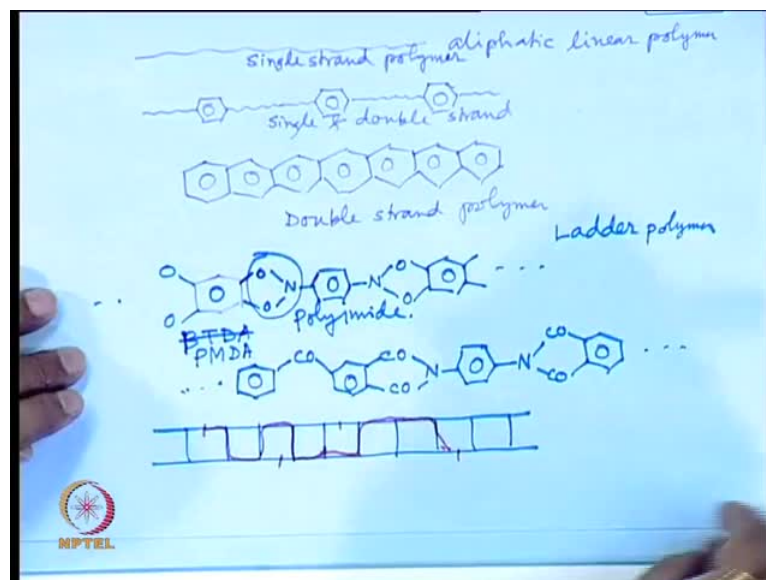
It is a product of Du Pont. What is Kevlar? This is aromatic polyamide made of who can say? Kevlar aromatic polyamide who can say? Karthikayen, why not? I told you in the class. Phenylenediamine and terephthalic acid, aromatic polyamide kevlar, what I show. If it is isophthalic acid polymer will be different. It gives the highest melting point, melting transition in that series.

So, you can take terephthalic acid, isophthalic acid and methacrylic acid meta meta structure, meta structure that means here you see in the para position if it is connecting

the meta position then the molecular symmetry is lost there and that using this methacrylic acid you will get nomex. It can give you a poly aromatic polyamide film and this gives you kevlar fiber. You write down the structure using methacrylic acid in a meta position here. Also you can have a para substitution, para phenylenediamine you can take meta phenylenediamine.

So, this you can, this way you can have... All are poly aromatic polyamides, but by virtue of your isomerization you are getting different melting transitions, different your mechanical properties. Now, this kind of, this is one polymer and you can have polyimide, these are the polyamide. You can have polyimides, I have shown in the earlier slides, earlier I have shown here, here you see.

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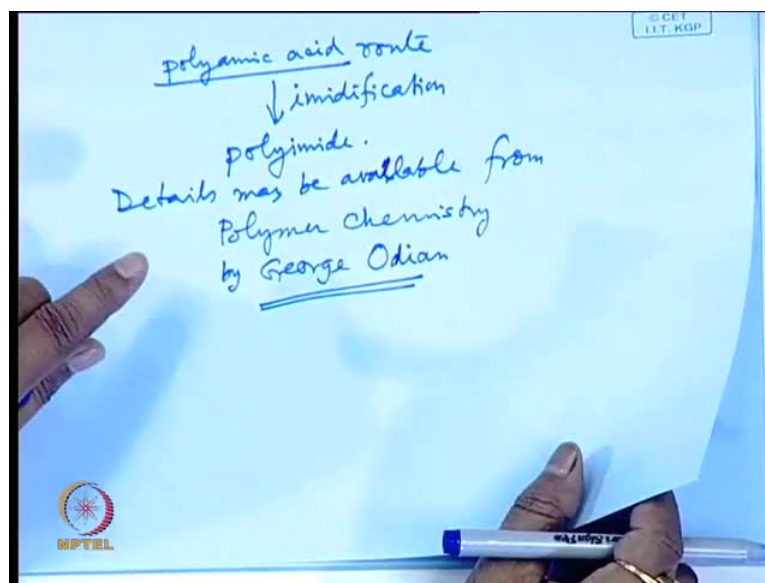


This is a polyimide say polyimide. Now, these are not so easily process able. You cannot melt it. So, main processing is not possible when this poly, this kind of polyamide were developed it was abandoned due to its lack of process ability, but scientists could develop its process ability by through the route of polemic acid. So, this amidrine once it is formed then it is difficult to further process.

So, what happens they took the same reasons, they they got a precursor polymer, pre polymer or polemic acid by reacting this actually this is BTDA, BTDA part, benzophenone tetra carboxylic dianhydride sorry PMDA I am sorry this is PMDA pyromellitic dianhydride. So, one can take pyromellitic dianhydride or benzophenone

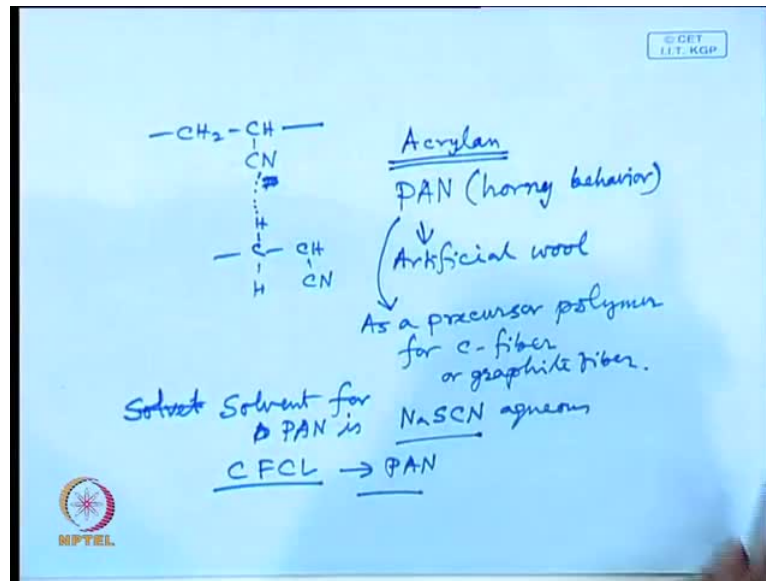
tetra carboxylic dianhydride. So, this can be used for making high temperature resistant polymers and there process ability is difficult. If you want to make polyamides then you have to go through polyamic acid route.

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Further imidification of this polyamic acid leads to polyimide. Details you will get sorry, you refer to this book. There are so details, so many things are there itself will be become a course. So, only here I can indicate for your information. Those who are interested you can take. What is this polymer, who can say? Not showing? This is actually, you are not getting in the screen.

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This polyacrylonitrile, actually polyacrylonitrile also enter into inter molecular hydrogen bonding nitrate is there. So, that nitrogen enter into hydrogen bonding although not that so strongly as you have seen in case of polyamides. That is why polyacrylonitrile PAN polymer. It is a horny polymer. This is used for making artificial wool, polyacrylonitrile. This also, this PAN is also used as a precursor polymer for carbon fiber or graphite fiber, graphite fiber.

The solvent for PAN is sodium cyanide NaSCN in which it is highly dissolved aqueous solution, aqueous aqueous sodium thiocyanate solution. There is one industry in haldia C F C L Consolidated Fibers and Chemicals Limited. They manufacture this PAN fiber, artificial wool. Acrylan, synthetic wool is known as... what it is called in a market. In a market we get it by in the name of what is that called? Acrylic fiber, acrylic fiber these are PAN fibers. Acrylic fibers are PAN fibers. So, that in this PAN fiber, in this PAN fiber you will find there is extensive hydrogen bonding between this nitrogen and hydrogen.