# Material Science
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## Indian Institute of Technology Delhi
## Lecture No 10
## Non-Crystalline solids

Well in the last class we were talking about the ionic crystals where you saw that the local stacking depends upon the relative sizes of the 2 ions which are involved and then discussing number of them with coordination 4, 6 and 8 we went on to see SI O2 which in its crystalline form we looked at quartz and its applications then we saw that usually SI O2 when it is molten and is allowed to solidify does it become crystalline? Usually it is non-crystalline in nature and that gives us the glasses, the window plane, the windscreens all these viewing windows which are made of silicate glasses are based on that some impurities which are called modifiers these are all oxides, they go and break the tetrahedral network and make the viscosity of the glasses lower and thereby lowering the glass transition temperature or the softening temperature of the glass.

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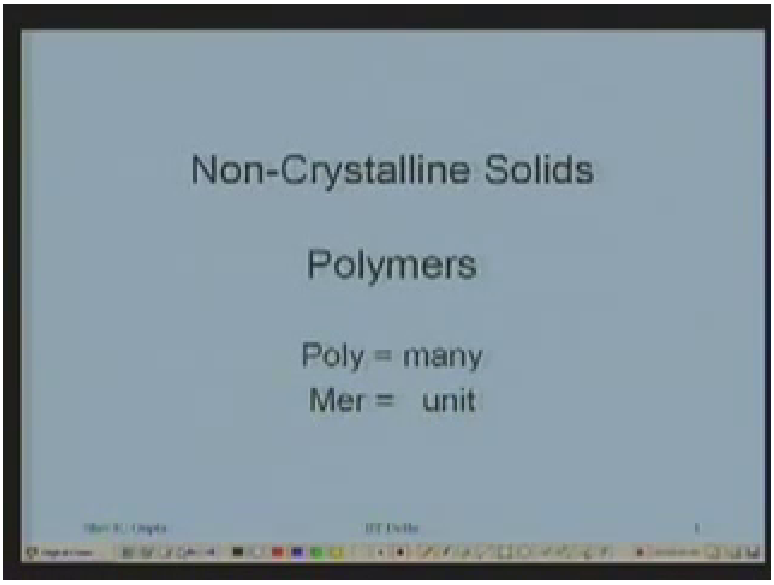

Non-Crystalline Solids

Polymers

Poly = many
Mer = unit

Continuing with the non-crystalline structures we move onto look at other non-crystalline structure which are polymers particularly the organic polymers, well as we have read in school polymers means many units Poly word means many and Mer means a unit, so the many units means many Mers are there could be in the range of 10,000 to 100,000 Mers in one molecule which we are all looking at that is why this called a polymer.

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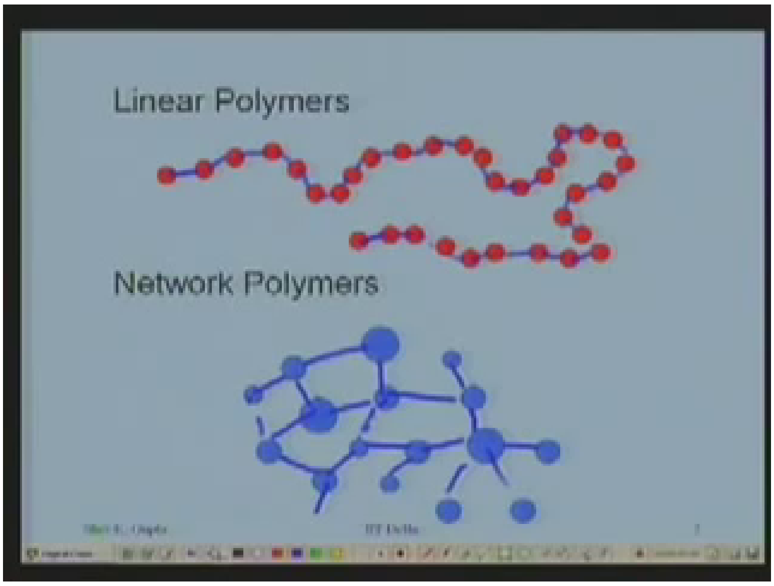

Linear Polymers

Network Polymers

Polymers have been classified in number of ways, one of the classifications on the basis of the arrangement of monomers in space if it is all along the line, so these are all monomers shown here and these monomers are joined like this along this line which is curved. This is a curvilinear line, it is called a linear polymer or chain polymer then another a network volume where the monomers are attached to other monomers in all 3 dimensions, so for example this one is attached to this, this one is attached to this and that may be somewhere else attached to this one attach here attach there and so on and so forth they form a network they are in different planes and they are forming a network in 3 dimensions.

Once they form a network like this in three-dimensions if the whole thing is one molecule, whole volume becomes one single molecule whatever may be the size of this molecule these are called the network polymers. So the basis of this arrangement of this monomers in space they are either linear or network polymers. What you notice is I have shown here one molecule here also this is one single molecule but there can be more than one molecule in here but they cannot be another molecule here will volume is one single molecule.

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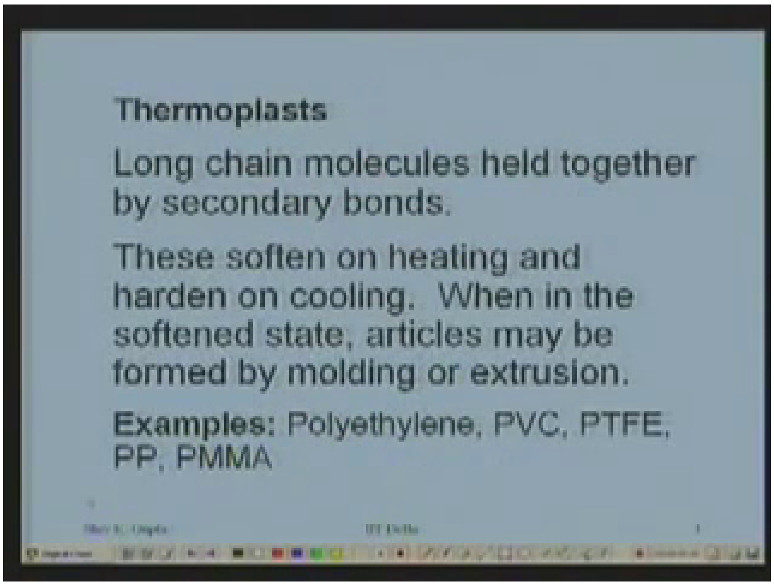

**Thermoplasts**

Long chain molecules held together by secondary bonds.

These soften on heating and harden on cooling. When in the softened state, articles may be formed by molding or extrusion.

**Examples:** Polyethylene, PVC, PTFE, PP, PMMA

Well the other classification on the basis of the behaviour to the temperature one of them is called thermoplasts as the name implies Thermo means heat plast it becomes more pliable, it becomes soft, so if we heat a material becomes soft and these are called thermoplasts usually their structure they are long chain molecules and between the molecules the long change is the only secondary bonds which are Van der Waals forces, all these as I said soften on heating and hardened on cooling it become more rigid you use number of such plastics, thermoplastics like you have seen some of your file folders their covers are very soft in some and they become quite rigid in winter as you cool they harden as the temperature rises they soften and in soften stage where they can be below the melting point of course it is possible for us to mould them and exclude them and give them the shape you want, so the processing becomes very easy for such materials giving them the shape, desirable shape is quite simple.

Some of the examples of this materials which you use polyethylene we simply call it sometimes polythene, polythene carry bags you usually use you have the polythene suitcases, containers made of polythene well pipe tube made of polythene then PVC polyvinyl chloride you have the insulation sheet made of polyvinyl chloride, you have also tubings made of Polyvinyl chloride, gramophones record can also be made of polyvinyl chloride. Then we have PTFE it is also falls under this category is the market is called Teflon polytetrafluoroethylene this is one material which has a very high softening temperature and it usually does not stick to anything so we have non-stick wares cooking wares you are having a coating of PTFE on them and because of its non-stick quality, to engineers they also wired good lubrication as bearings.

Polypropylene is another such material which is long chain polymer and thermoplasts, well you make the these days the dashboard of the automobiles, the bumpers of the automobiles of polypropylene, well sportswear are also made of polypropylene these days then we have polymethyl methacrylate which is also called the Plexiglas or usually wrist watches you have the windows on these they are made of this plastic material which is called Plexiglas it is a very transparent material and it is substitute for the silicate glasses, it is soft, pliable and this is polymethyl methacrylate. So these are some of the thermoplastics which are there.

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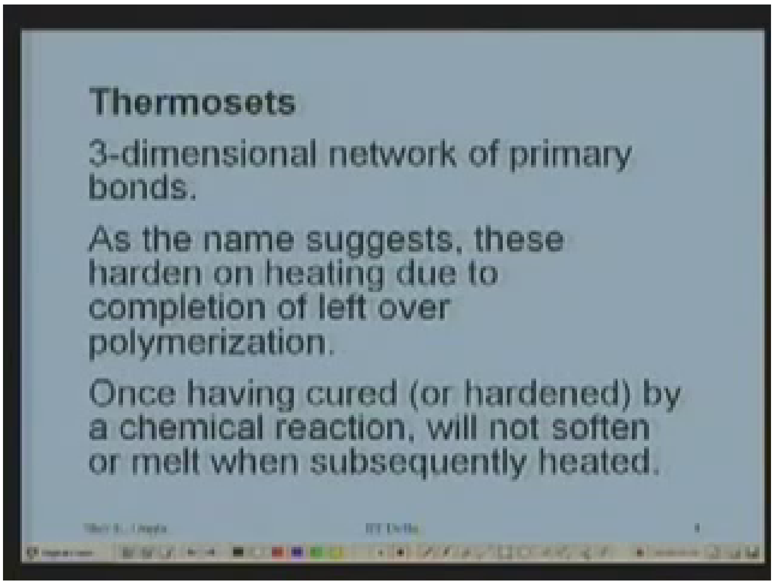

**Thermosets**

3-dimensional network of primary bonds.

As the name suggests, these harden on heating due to completion of left over polymerization.

Once having cured (or hardened) by a chemical reaction, will not soften or melt when subsequently heated.

Then on this similar behaviour or the basis of heat we find another materiel which are Thermosets structure wise it is usually in dimensional network of primary bonds like what I showed the network polymers and as the name Thermo sets you heat Thermo means you heat and sets means it hardens, so as you heat it hardens and why it hardens is? If there is any leftover process of polymerisation that goes to competition with the available thermal energy by heating and these are becomes a complete molecules, single molecules three-dimensional network. (())(9:51) if there once made as a single molecule you give it a shape whatever shape you give sometimes the process of polymerisation is made in a through a chemical reaction. Once it is given a shape it forms that shape it is before it can melt or you will not heating it degrades and combines with the atmosphere oxygen and degrades there is not possible for it to melt so easily because they are all primary bonds Sp 3 bonds it do not break so easily, so it is soften on heating rather even before it can melt it degrades.

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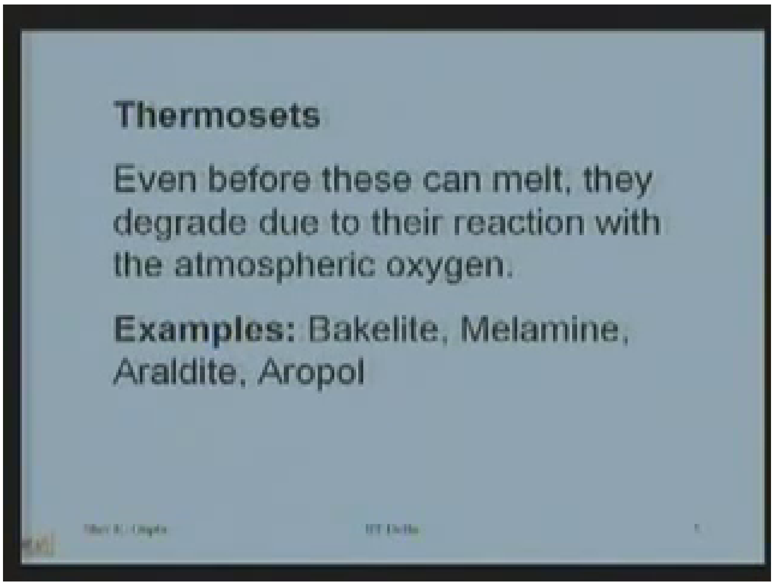

**Thermosets**

Even before these can melt, they degrade due to their reaction with the atmospheric oxygen.

**Examples:** Bakelite, Melamine, Araldite, Aropol

Even before they can melt they degrade due to the reaction if the atmospheric oxygen, it is a reaction you must have seen we have there using the bakelite is one such material and making the switches. When you put switch on and off there is usually sparking taking place and that is why sometimes the contact we lose either it could be constant sparking is going on if that is happening you smells sometimes something and it is burning of bakelite, so with the heat instead of softening it starts burning you know that is it degrading it is combining with the atmospheric oxygen and burning off, so that is the kind of thing that happens in thermosets they do not…

It is not possible for them once you have given them the shape it is not possible or you to join them by heating process which you have done with the thermoplasts, thermoplasts let us say PVC, it breaks can simply the broken pieces together heat it a bit and just allow them to come together for a while and this will all the chains will intermingle again it will become one piece it is possible for it to give treatment like that to this or you can give it a reshape it but you cannot initiate this materials. Bakelite, Melamine, Araldite, Aropol these are some of the network polymers which are thermosets and these cannot be reshape.

When it is sold these materials are sold in the market as a raw material they have to be sold as partially polymerised material, if they are fully polymerised cannot do anything with them, so in partially polymerised chips which are available you put them in a cavity of a dye press it and heat it, during the heating process whatever is the polymerisation process incomplete that goes to completion because of this heat under the pressure you keep it and it will get take the shape of the dye and when the final product form and that final product is one single molecule right, so therefore is not possible by heating process to join these back you cannot remould them, if they are broken they are useless you will have to simply throw that you cannot reuse it.

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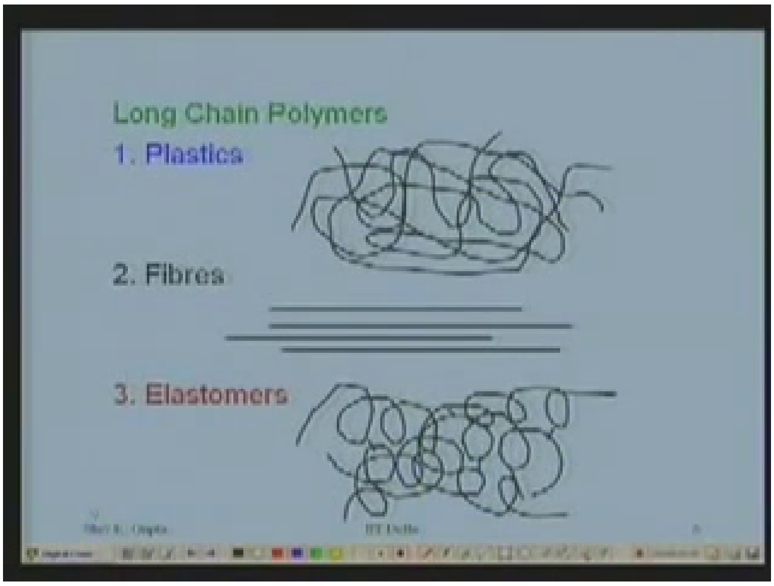

Long Chain Polymers

1. Plastics

2. Fibres

3. Elastomers

Now on the basis of the arrangement of the long chain in space, the long chain polymers we will talk about today because these are the ones which can as engineering materials you can use them more quiet and reuse them also. Plastics in which chains are placed zigzag in three-dimensional space and between the chains there are only secondary forces that is Van der Waals forces there are no other kind of bonds between them only Van der Waals forces and primary bonds are along the length of the chain and chains are placed zigzag in the three-dimensional space.

These are the plastics like some of them I have named already Thermoplasts which I talked about fibres are the along chain polymers but here each chain is arranged parallel to the other though they may not be of the same length they may be of different lengths but they are arranged parallel to each other and they are held parallel because of the hydrogen bridges between them at a few places and they maintain their length because of this hydrogen bridges which come at regular interval there is some kind of periodicity in that and this is the remain parallel to each other and these fibres are very strong in the direction of the axis of the fibre because in the axis of the fibre when you try to pull you are pulling only the primary bonds. Only when you go cross you are pulling the secondary bonds, so along the axis the fibres they are very strong, so this you have nylon, you have cotton, you have deacon all these things are fibre, the natural fibre like jute you can have the…cotton is also a natural fibre.

While we have the 3rd category of long chains which are elastomers, really speaking they are long chains but in between we have few cross-linked like this between chains various chains like that, these cross-links are primary bonds between the chains that means it is something like if you have a long chain but in places is trying to become network, so it is between the 2 it is not if I do the cross-linking at all places then it will be absolutely a network polymer but it is only a few places these cross-links are there and as a result and the chains are quite coiled not very zigzag they are coiled and these materials when they are stretched, they are stretched 300 percent 400 percent of the original length and when you release the force they come back to its original shape and size.

It is different from the behaviour is very different from the other 2, if you are able to stretch this and then try this then cut a strip from a polythene bag and stretch that strip you will be able to stretch it but it will not come back. Take a piece of rubber band you stretch it, it comes back and this coiling which is there on stretching is getting uncoiled and this primary links are making it a comeback you know that we will see in detail when we come to the elastomers and these are the 3 basic arrangement of chains in space in as far as structure is concerned in a long chain polymers and because of the arrangement these are called plastics or called fibres or is it called elastomers, okay because they behave in a rubber like manner so I called them elastomers.

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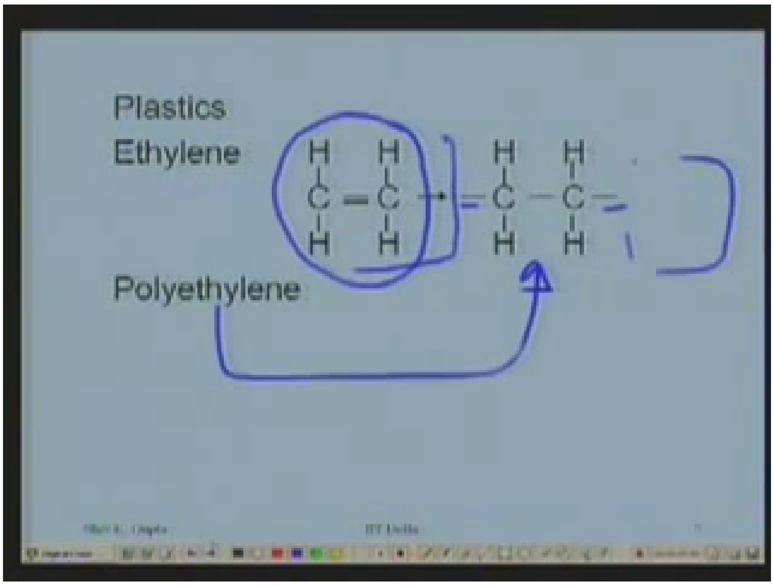

Plastics

Ethylene

Polyethylene

Now we shall look at the plastic 1st and then we will go over to look at the fibres some other fibres. Easy for us to look at the plastics with the help of a monomer of ethylene C2H4 there is 1 double bond and this is one molecule of ethylene then we polymerised this, this double bonds saturates becomes a single bond but provides a single bond here and a single bond there to which I can connect and another monomer there I can connect another monomer here and this chain can extend on both sides, once that happens I refer to this as polythene or polyethylene otherwise this molecule is ethylene molecule which is a monomer right this is what I mean by polymerisation that this double bond is saturated provides a links on both sides and those links are connected to other monomers in the same fashion that is what it is a polymerisation process.

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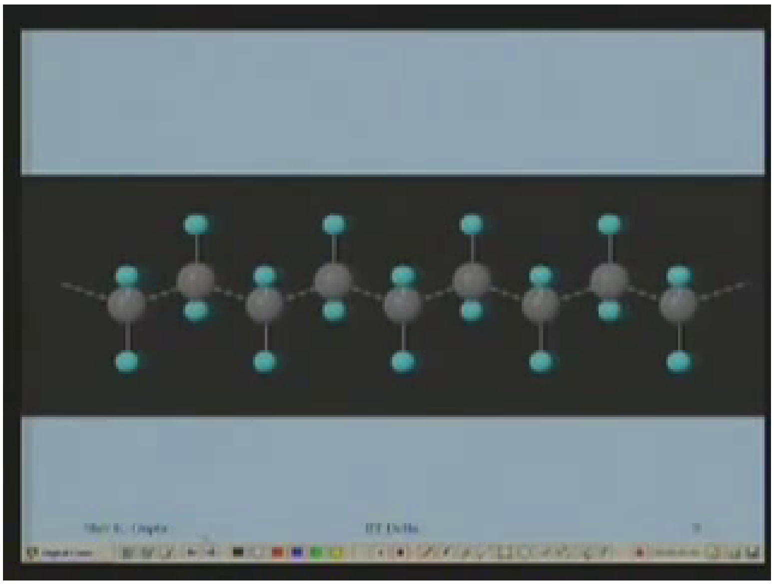

Well this is what is a polyethylene molecule chain, rather this is one monomer that is another monomer, 3rd monomer, 4th monomer so on and so forth these monomers are connected here this, so this is all the carbons I am showing as black ones or the grey ones and these blue ones are the hydrogens.

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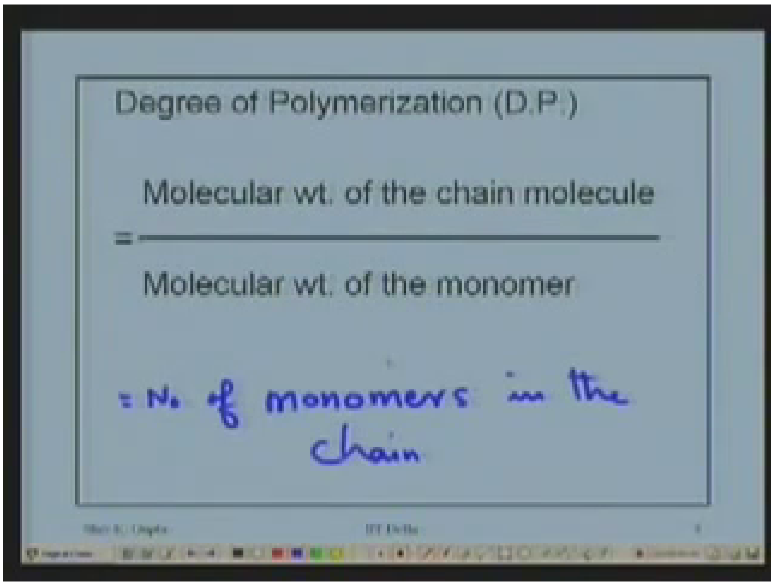

Degree of Polymerization (D.P.)

$$= \frac{\text{Molecular wt. of the chain molecule}}{\text{Molecular wt. of the monomer}}$$

= No. of monomers in the chain

This chain how many such monomers are there is called the degree of polymerisation of the chain, so if I know the molecule weight of the chain molecule divide by the molecule weight of the monomer it becomes the degree of polymerisation. In other words it is equal to the number of monomers in the chain but in the solid no 2 chains are the same length, no 2 chains have the same degree of polymerisation therefore we work usually on terms of the averages or the weighted averages find out these degree of polymerisation or average degree of polymerisation. Yes please?

Student: This will be equal to number of polymers (())(21:44) till (())(22:06)

Prof: There is a difference between I am not talking about the processes of performing polymers, in school we have already of course studied there is an additional polymerisation and there is a condensation polymerisation, here we are referring to the additions what I talked about polyethylene is only addition, okay. So this we are referring to the addition and therefore it is molecule weight of the chain molecule and molecule weight of the monomer will work in this case, when you talk about the condensation polymerisation will normally be forming network polymers, alright.

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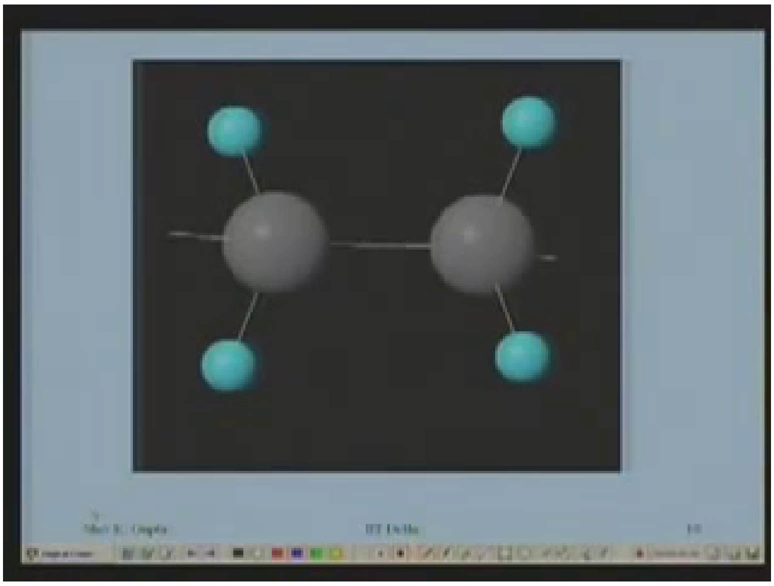

Well this is actually the one monomer unit and on the basis of which I am going to talk about other plastics as well, 2 carbons 1 and 2 and then this is a one-side growth, second side growth, 3rd side group and the 4th side group, numbers 1, 2, 3, 4 you can make in any order 1, 2, 3, 4 it has the 4 side groups which are hydrogen in case of polyethylene and these are the 2 corners, so for all others would I do this I call this a side group R1, side group R2, side group R3, side group R4 and see what different plastics I am able to get by changing these R1, R2, R3 and R4.

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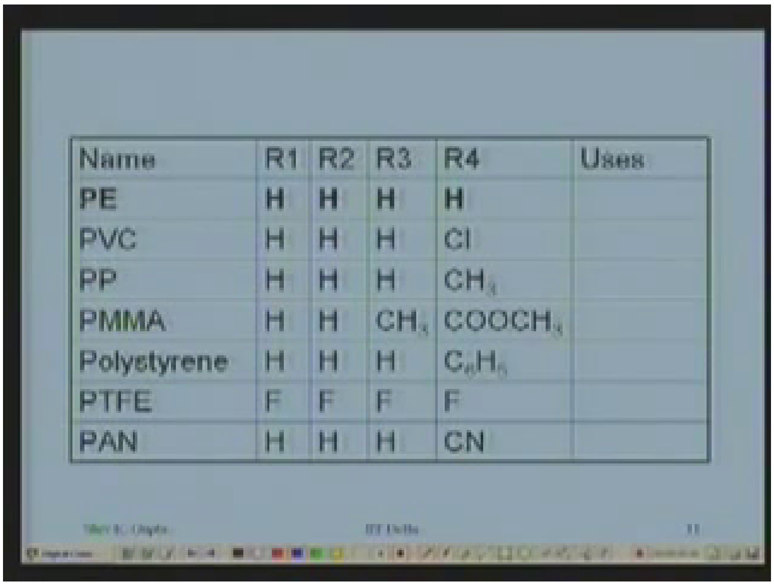
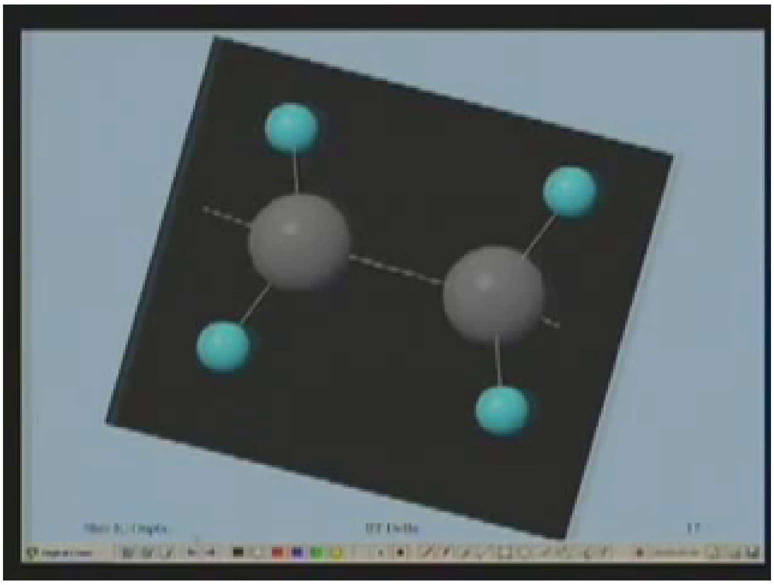


| Name | R1 | R2 | R3 | R4 | Uses |
|---|---|---|---|---|---|
| PE | H | H | H | H | |
| PVC | H | H | H | Cl | |
| PP | H | H | H | $CH_3$ | |
| PMMA | H | H | $CH_3$ | $COOCH_3$ | |
| Polystyrene | H | H | H | $C_6H_5$ | |
| PTFE | F | F | F | F | |
| PAN | H | H | H | CN | |



For polyethylene as we have start talking about R1, R2, R3, R4 are all hydrogen side groups that is what I have showed you and that is on the basis of each we are going to talk about the others and I already said that we can use these materials for containers, carry bags, et cetera that is where we are making use of it even the suitcases we can make out of it. Polyvinyl chloride is the next one which we shall look at whether 3 side groups are hydrogen, hydrogen and hydrogen R1, R2, R3, 4th one is the chlorine atom which is little bigger one as compared to hydrogen and this forms again a chain molecule it is used well it is a rigid material though and can be used for your piping, sheets or the gramophone record et cetera, insulation is the greater use for the PVC in electrical insulation of the wires. Well this is made more pliable by addition by we make some additions of either copolymers to it or we add some (())(25:25) to make it pliable and soft usually it is a rigid material in the pure form.

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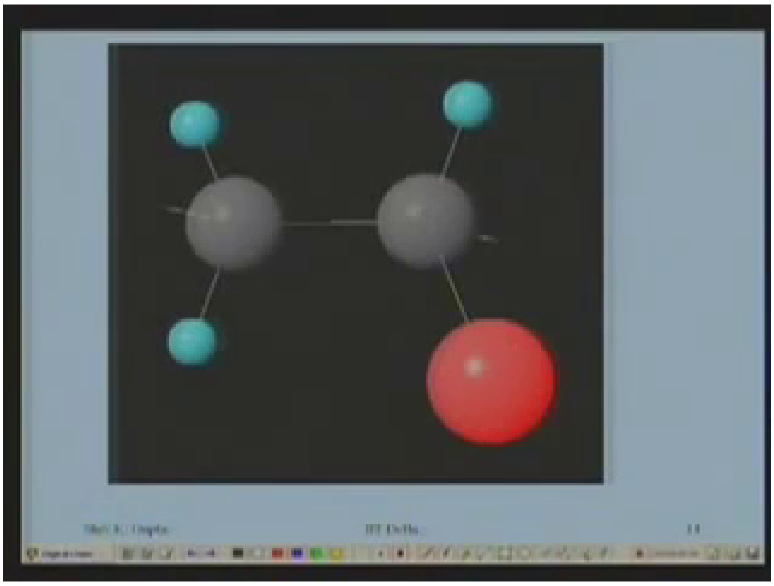

And we will see the molecule R1, R2, R3 are hydrogen and the 4th one is the chlorine it is a much bigger one bigger than carbon and that repeats and these are the repeating can be added here and there. Notice that one important thing or carbon these 4 bonds which I have to extend it is our Sp 3 bonds and they are not in a plane you can see that it starts here goes out word comes in front goes back this is also going backwards, so this 4 bonds are Sp 3 bonds tetrahedral bonds. See it is the same thing here the tetrahedral bonds.

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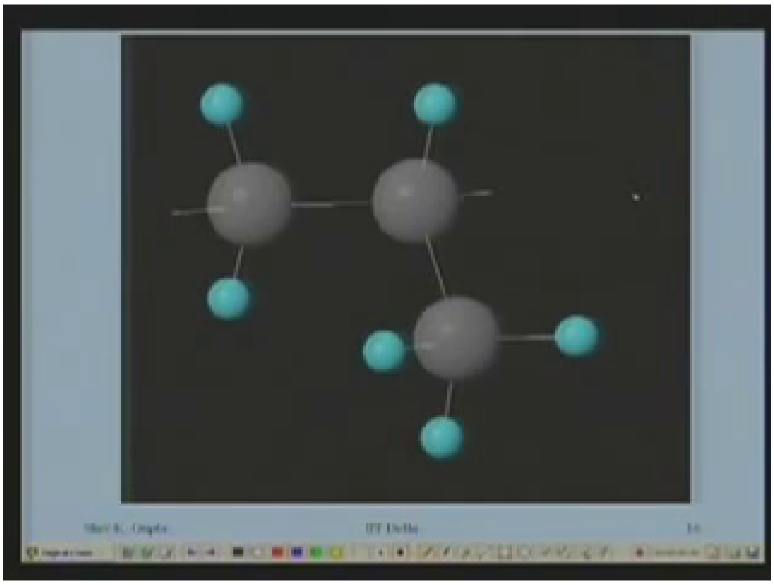

Next one should be polypropylene, next one should be polypropylene and polypropylene has a side groups hydrogen, hydrogen and hydrogen and the 4th side group the big one you see it is CH 3 a bigger one and the arrangement in the space is going to be little more ticklish remains zigzag completely and this is polypropylene is a material used as I said in dashboards, polypropylene is the material used in bumpers of the car, polypropylene is also using making buckets and the plastic wares you may use and these days polypropylene withdraw the fibres, spins the fibres out, the melt is made to drop on a rotating disk and fine fibres of the propylene are taken out then it is converted into Staples and you can make a thread out of it and you make the sportswear.

Polypropylene does not absorb water at all but in the capillaries formed between the fibres lot of water can be in the surface tension and that is why these sportswear can absorb all your sweat when you are working or you are running or you are playing we sweat a lot and now the sweat can be absorb by them and when you jerk it, it becomes absolutely dry just simply by jerking or shaking you can remove all the water from between the fibres because it is held by surface tension alone that is what towelling material is also very good, towelling material soft towelling material makes out of this it can absorb lot of water but it can become very dry very soon.

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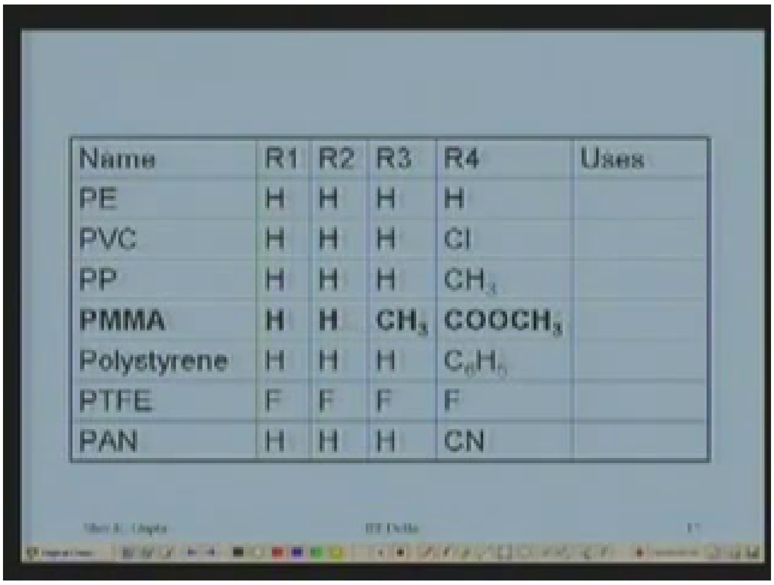

| Name | R1 | R2 | R3 | R4 | Uses |
|---|---|---|---|---|---|
| PE | H | H | H | H | |
| PVC | H | H | H | Cl | |
| PP | H | H | H | $CH_3$ | |
| **PMMA** | **H** | **H** | **$CH_3$** | **$COOCH_3$** | |
| Polystyrene | H | H | H | $C_6H_5$ | |
| PTFE | F | F | F | F | |
| PAN | H | H | H | CN | |

Next is polymethyl methacrylate, 2 side groups are hydrogen 3rd one is the CH 3 just as I showed you and the 4th one is COOCH 3 is still bigger group, this is also called the Plexiglas and I told you that windowpanes or the transparent windows can be made out of this material, so it is a very transparent material.

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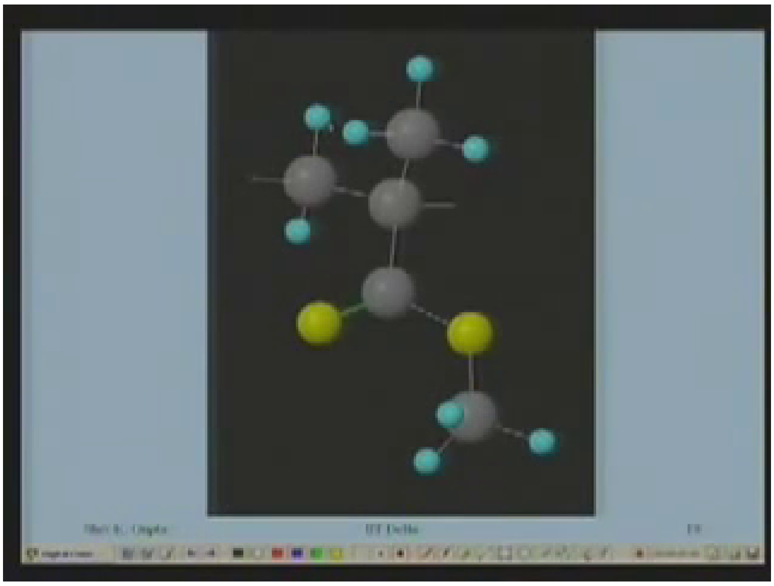

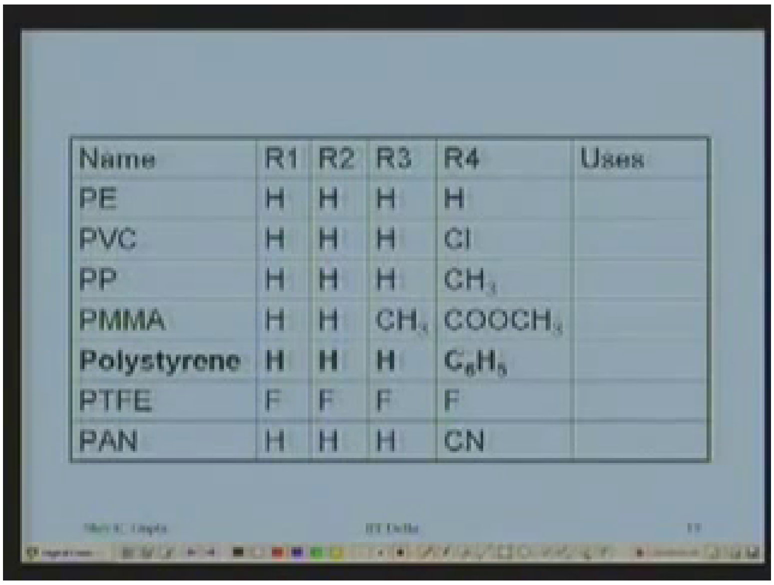

| Name | R1 | R2 | R3 | R4 | Uses |
|---|---|---|---|---|---|
| PE | H | H | H | H | |
| PVC | H | H | H | Cl | |
| PP | H | H | H | $CH_3$ | |
| PMMA | H | H | $CH_3$ | $COOCH_3$ | |
| **Polystyrene** | **H** | **H** | **H** | **$C_6H_5$** | |
| PTFE | F | F | F | F | |
| PAN | H | H | H | CN | |

These are the one and 2 side group 3rd one is CH 3 4th one is COOCH 3 oxygen atoms this okay this is carbon and this is again hydrogen CH 3 everywhere you see carbon is having tetrahedral bonds this is a double bond with oxygen but that is a single bond there and this is a window material. The next one as polystyrene where 3 side groups are again hydrogen the 4th one is benzene ring, these polystyrene is very hard and transparent material but in that form we do not use it, we use it in the form of foam sleeve which is called Styrofoam and Styrofoam is what is used for heat and thermal insulation, it is used in packaging as a thermocol that is what it is the Styrofoam is and if you look at its unit monomeric unit in polymer.

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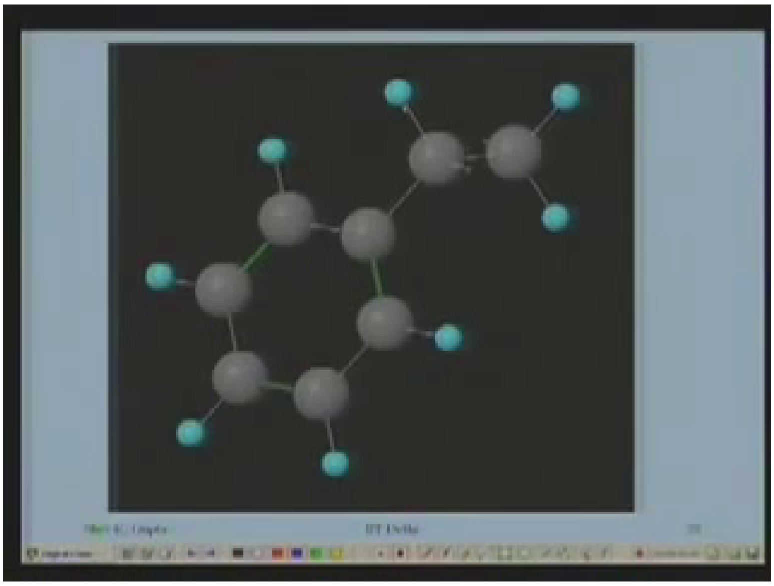

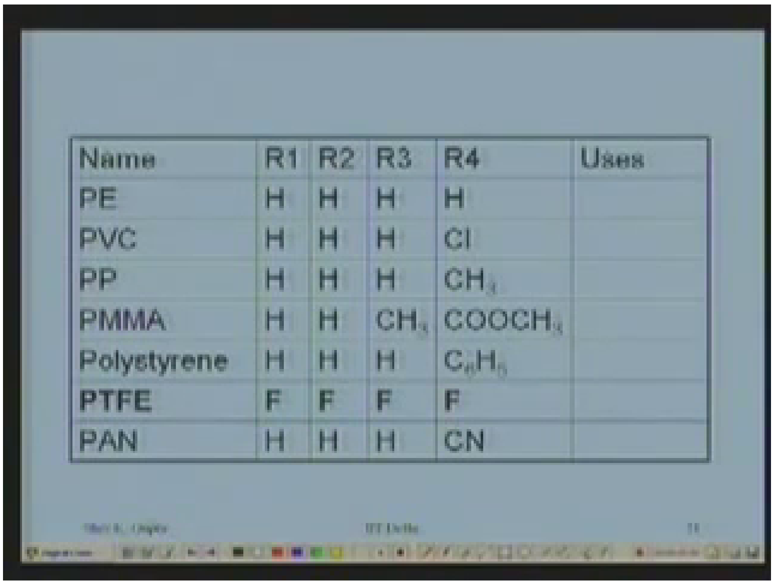

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| Polystyrene | H | H | H | $C_6H_5$ | |
| **PTFE** | F | F | F | F | |
| PAN | H | H | H | CN | |

This is 1, 2, 3rd 3 hydrogen side groups the 4th one is a benzene ring here 6 of the carbons these double bonds which of course will be rotating and these are the hydrogens connected. Important thing to be seen all collections are through Sp 3 bonds. Polytetrafluoroethylene is the next one as engineers has always told you that we use it for all the side groups are fluorine and we use it its non-stick quality in bearings we make the sliding blading, we make the rotating bearings journals can be rotating steel journals can be rotating in a bearing made up of Polytetrafluoroethylene that is Teflon and it will keep working with very small fraction.

It provide a coefficient of friction with steel less than half a percent that is of the order of 0.005 coefficient of friction or between 0.005 and 0.01 that is the coefficient of friction we have is very small. In other words as compared to the other metal bearings where the coefficient of friction could be high in the range of 10 to 30 percent is much better one only thing is is fabrication is a problem because softening temperature is around 375 and fluorine is a very reactive material hydrochloric acid which forms is a very reactive material, the container in which you have to keep is a problem.

Anyway we do have a lot of manufacturing going on for the Teflon these days and we make use of it. Civil engineers exploit this in push launching of bridges, the (())(32:45) they make is let us say the span of shore and the peers are already made in the stream over the peers instead of lifting it with a crane and putting it over the peers, it can simply be slided with the help of screw jacks or the hydraulic jacks the capacity of the hydraulic Jack has to be just one percent, if the coefficient of friction is 1 percent has to be only 1 percent now the deadweight.

If I have to lift it with the crane the capacity of the pain should be a weight of the span itself which could be a few tons instead that one percent of it I can have hydraulic jacks and we can simply push it like this over the peers, so pads are made of Teflon which I put on the peers or which it the steel Bridge can slide easily right that is where the push launching of bridges where the manufacturing or rather the labour cost and the installation cost becomes very small if you use that and civil engineers all over the world or exploiting this.

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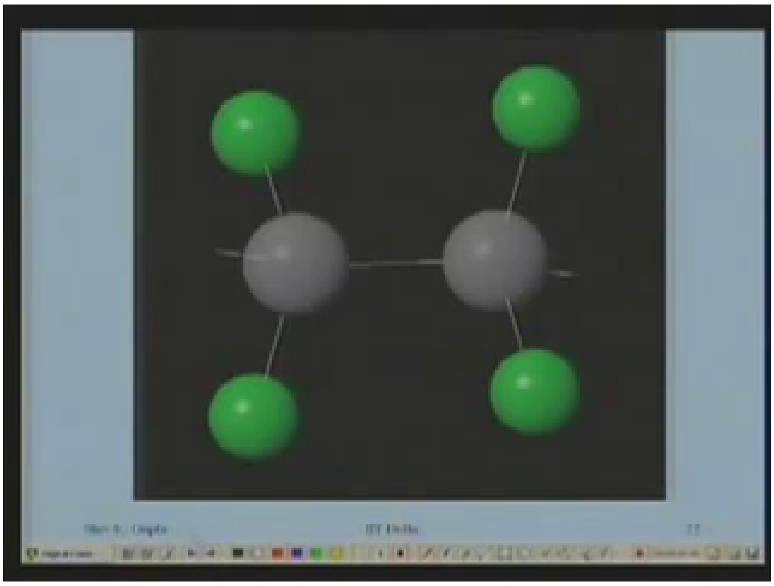

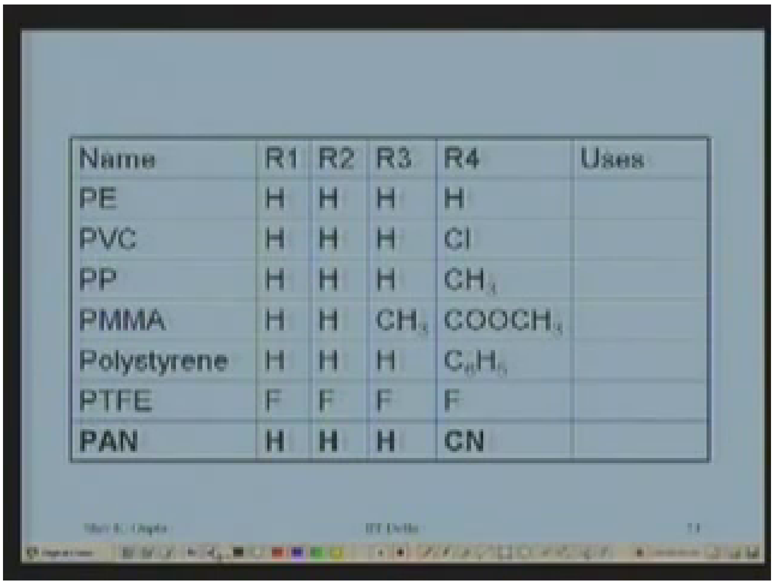

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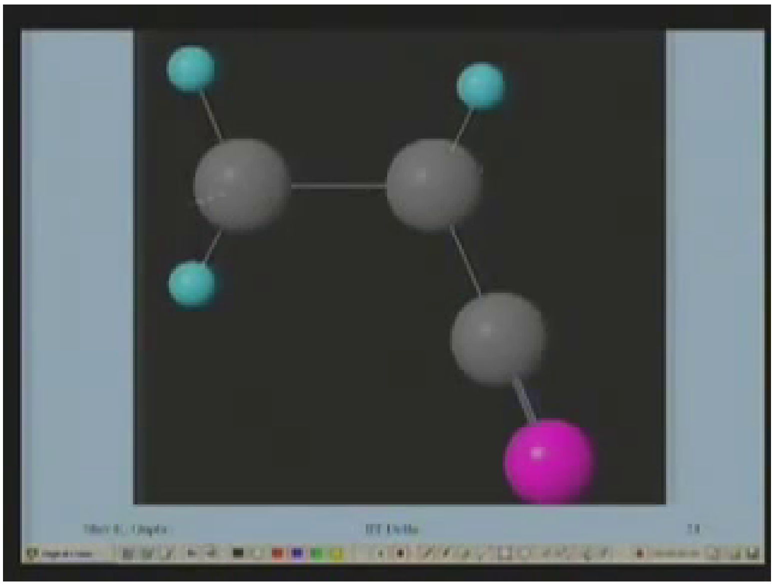
| Polystyrene | H | H | H | $C_6H_5$ | |
| PTFE | F | F | F | F | |
| **PAN** | **H** | **H** | **H** | **CN** | |



Then comes next polyacrylonitrile again a very important material as a matter of fact it is the starting material to make the carbon fibre, carbon fibre is not produced from graphite but it is produced from a polymer like polyacrylonitrile where the this this is Teflon of course where the 4 side groups are fluorine good into polycal and nitrile which is substitute for wool and we use it as a substitute for wool this material, this is the side group R1, R2, R3 which are hydrogen, the 4th one is CN, this is nitrogen this is carbon. This is polyacrylonitrile the substitute for the wool and is used as a starting material for making carbon fires it removes slowly this nitrogen hydrogen and make it a chain of carbon, okay and ultimately in three-dimensions it will form the Sp 2 bonds of carbon and form a fibre.

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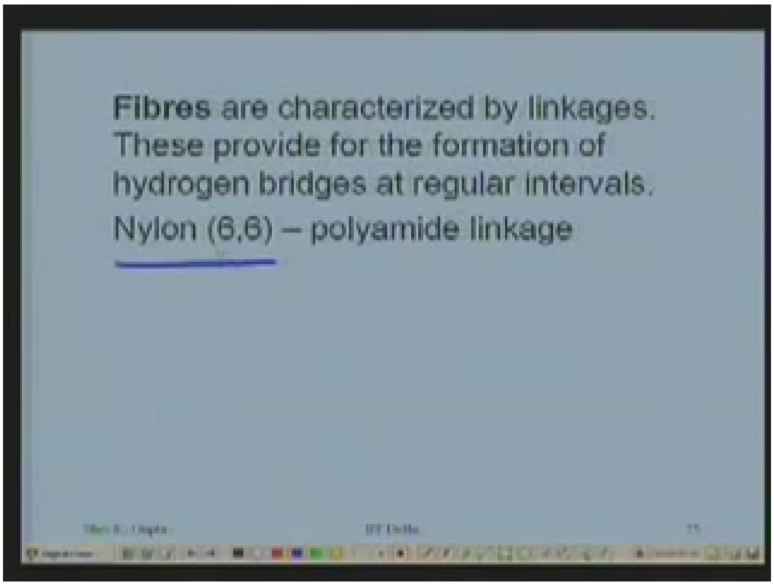

**Fibres** are characterized by linkages. These provide for the formation of hydrogen bridges at regular intervals.

Nylon (6,6) – polyamide linkage

Alright these are the plastics some of the plastics not all the plastics I have talked about that the ones which are easy and simple one to understand these days we have lot more plastics, engineering plastics which we have exploited and they have provide us good strength in making the engineering components like gears, excels, et cetera we can make all these materials. Then we move on to the next kind of a long chain polymer, the fibre as he said to start with these are characterised by the linkages which create hydrogen bridges between the chains that is important we shall look at with the help of nylon 6, 6 we call it 6, 6 because it is the backbone of the chain, there are 2 sets of carbon atoms having 6 each in a group, these 2 groups have 6 carbon atoms in each group that is why it is called 6, 6 and they are linked with polyamide and that is what polymer linkages let us look at that.

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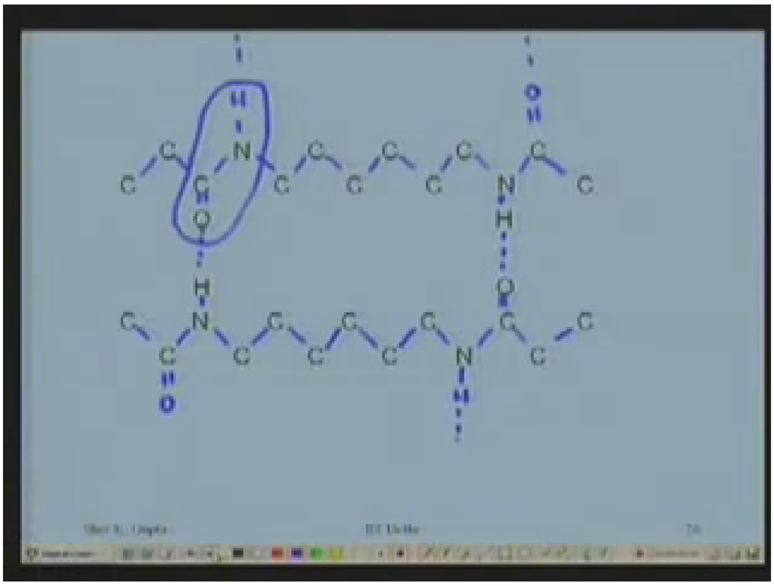

Well here is this long chain, similarly this one would be…I have not shown the side hydrogen groups 2 of them which will be there for each one of these carbons you know. See nitrogen has 3 bonds, one hydrogen, one with carbon, one with carbon. Oxygen has 2 bonds with this carbon double bond, similarly this oxygen has double bond, this is my linkage in the backbone I have 1, 2, 3, 4, 5, 6 chains is carbon and then another set of 6 1, 2, 3 another 3 like that similarly 1, 2, 3 and so on and so forth 6 of them will be the next where this carbon is also counted within the linkage which is a…

Now you see this hydrogen here and oxygen here when they come, hydrogen is just a proton (())(38:04) share the electrons here it is only a proton, okay and that proton forms a hydrogen bridge with this oxygen like this and this will be forming hydrogen bridge here that will be forming hydrogen bridge there it will also be forming hydrogen bridge there, so there is a constant interval at which these hydrogen bridges are coming, okay it is going to be I think this will have an oxygen here. So these 6 carbon atoms coming then the next 6 carbon and between 6 there is a link formed and all the chains get linked like this, it forms a fibre that is what we understand that is how all the fibres are made they are straight and fibres.

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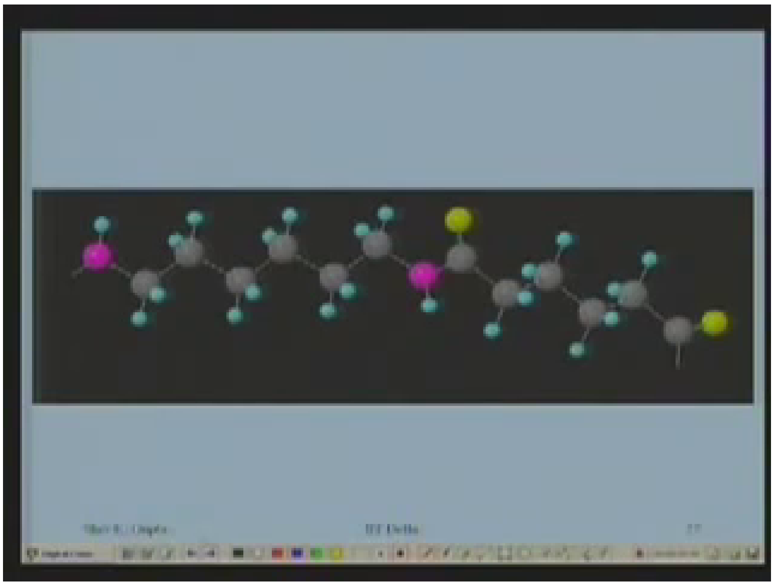

And you know this nylon is very strong and we use it for making ropes, et cetera and this is what I have shown is in the form of these balls, these are all carbons 3, 4, 5, 6 and I have this nitrogen here there is a hydrogen bonded to one and one carbon here and one carbon there and this is carbon which has an oxygen here double bond, so 1, 2, 3, 4, 5 and 6 again 1 double bond and then there will be here there will be nitrogen connected to this and to the double bond here so it will be only (())(39:53) but it will be carbon again but that carbon would be bonded to the…should be nitrogen there somewhere. This is nitrogen yeah that is going to be nitrogen here, here it will be the nitrogen so that is how this every in between every 6 there is a link and this nitrogen or this hydrogen and the oxygen will form a hydrogen bridge and that would be coming at the constant intervals everywhere. Same is to with cotton (())(40:36) and all these fibres we have this all true with all of them.

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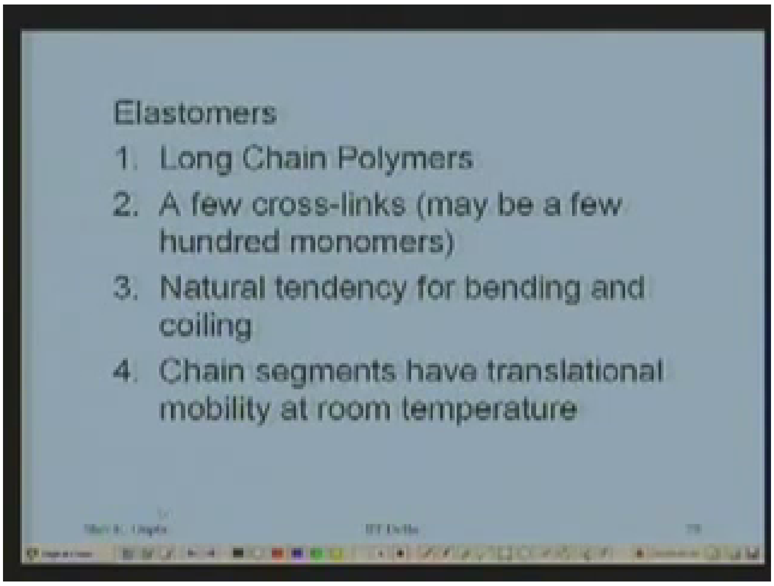

Elastomers

1. Long Chain Polymers
2. A few cross-links (may be a few hundred monomers)
3. Natural tendency for bending and coiling
4. Chain segments have translational mobility at room temperature

Then the 3rd one we come to the elastomers rubber like elasticity they are showing, structure wise they have long chain polymers it is important I said there is somewhere between but basically they should be long chain polymers, however the chain there should be few cross-links and these cross-links are at the distance of few hundred monomers it is not very close if I do that in every monomer it is a network polymer it is no more long chain polymer and that network polymer would never behave like an elastomer, it is behaving like an elastomer because of these conditions which I have listed here, so long chain polymer and there are few cross-links that is added distance of few hundred monomers.

Thirdly the monomer and subsequently this added monomers to form a chain provide a natural tendency for bending and coiling in the chain. We shall look it with the help of 1 natural elastomer which is polyisoprene there is a natural tendency of bending and coiling it is essential and lastly the chain segments which are there must have translation mobility at room temperature if the material has to behave like an elastomer otherwise these conditions can be satisfied for a few degrees by some most of the polymers before they melt that does not make them elastomers if in the room temperature when I can use them, room temperature could be 4 degree centigrade, it could be 44 degree centigrade (())(42:46) as long as it can continue to work like rubber whether it is a tire of truck or a tire of an automobile or it could be the tube or it could be eraser or it could be rubber band, I should be able to use it like an elastomer right.

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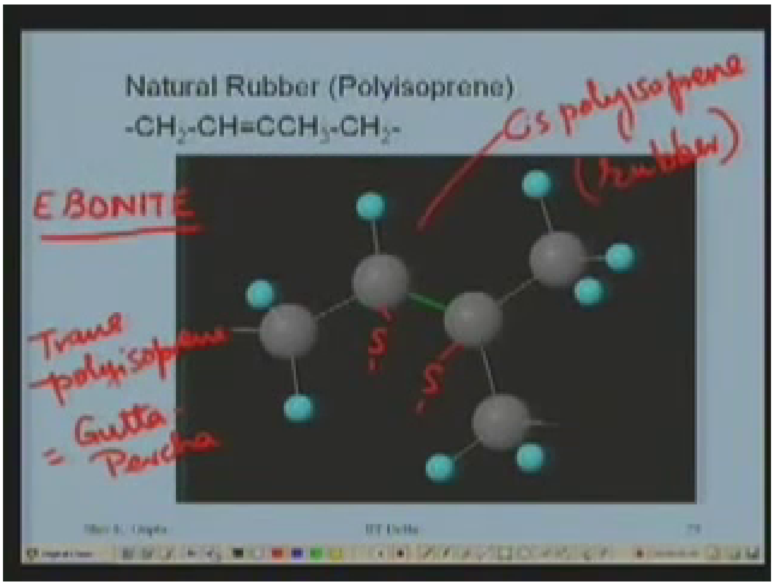

Natural Rubber (Polyisoprene)

$-CH_2-CH=CCH_3-CH_2-$

So that we shall see all these conditions satisfied 1st in the case of polyisoprene, it is naturally found material polyisoprene how do we extract it from the tree rubber plant, it is taken out in the form of the liquid, it is taken out in the form of liquid, so at room temperature these chains are flowing translating with respect to each other, so that condition number 4 is already satisfied, chains are translating at room temperature as it is taken out it is a liquid and in this form I am not able to use it as an elastomer right, alright.

Then 3rd point which I said from backward I am looking at should be natural tendency for bending and coiling that is what I show here this is CH 2 is here CH is this and then C this is double bond with carbon which is connected to CH 3 which is here which is rather here then connected to carbon another carbon which has 2 hydrogens and then again this will be linked, so the one or the next monomer comes here, another monomer comes there between this is like this, this requires more space than the hydrogen there is lot of space in the plane here all-around, around the double bond if you go around there is lot of space but because it is a double bond rotation is not possible.

So in order to find a space or this bigger side group is bends about this double bond, double bond is not straight, double bond bends above this so that provides a space for this to be placed so that provides a natural tendency for it to bend and coil because of this one side group which is bigger than the others it provides tendency for bending and coiling but there is enough space here what if I straighten it up I have lot of space here but between this and this hydrogen tries to find a space and that space is (())(45:43) binding it is been shown by little more binding, it is not going to be so much of a bend because after a few means tens or few hundreds I get one called form, so this is how the coils are formed there is a natural tendency for the chain to bend and coil right that is the point number 3.

Then the point number 2 this is how I get the material from the tree and it is a liquid, in this form can we use it as a rubber band? Can we use it as an eraser? Can I use it as a truck tyre? No. So we have to provide a few cross-links in this and these are possible to provide because there is a double bond here. If I break this double bond make it a single bond here the bonds for this carbon and that carbon, a tetrahedral bond will have to be formed. Both these carbons have one unsatisfied bond once this double bond is saturating and this is provided by when this liquid taken out from the tree is to be made useful rubber what we do is we vulcanize it.

Vulcanisation process is simply heating this rubber liquid or polyisoprene liquid with sulphur. What sulphur does is it breaks this double bond and bonds with this carbon and this carbon, that sulphur (())(47:44) to burns so this 2nd bond of sulphur goes and bonds of somewhere else, it may go to another monomer of another chain both of them may go to a same monomer both of them may not go to the say monomer they may go to different monomer of different chains, so there is a link which is called the cross-linked when this chain and another chain. Cross-linked is formed because of this breaking out in the (())(48:17) bond, 2 single bonds are formed which are joined by sulphur that is the role played by sulphur in this during the process of Vulcanisation.

Now it becomes a solid mass which can be used as an elastomer, it is going to be a soft rubber if I do the cross-linking half a percent it will be a hard rubber if I do a cross-linking 5 percent, 10 percent it will be still harder if I do it 20 percent but if I do the hundred percent cross-linking every double bond is broken to form a single bond this will become a network because this is connected to something else that in turn will be connected to something else like that the whole thing will become a network.

So the 2 rubbers are very different after complete networking, after complete this thing this material is called ebonite and you know ebonite is a rigid material it is not an elastomer, so that is why I said I want the cross-links after every few hundred monomers, a few thousand monomers softer few thousand it will be very soft rubber, rubber band you wanted to be soft there will be less cross-linking like eraser is little harder right tire of a truck or an aircraft you wanted to be hard but the tube inside you do not want that to be so hard, it is soft so you have done more cross-linking more Vulcanisation for the tyre and less for the tube that is what you have done and that is what it is. You can see that now…

Student: There is sulphur only (())(50:19).

Prof: Pardon.

Student: There is sulphur only (())(50:22).

Prof: No, not necessarily I can also provide the cross-links with the help of small molecules rather than sulphur is acting as one atom you can consider it (())(50:31) molecule, I can provide a small chain, so there are variety of rubber I am just giving you an example of one.

Student: (())(50:38).

Prof: Ebonite is sulphur this whole thing will become completely vulcanised it will become ebonite right, so that it is then there are 2 forms of this material isoprene in one case this CH 3 group is coming always on one side of the chain that is called the cis arrangement or the cis polyisoprene that is what my rubber is, it can also come in the form of a trance that in one monomer it is on this side on the other monomer it is on the other side alternately it is coming it is called the trance polyisoprene in that situation it tends to become a straight-chain and becomes a rigid material then it is no more a bend and coil it is not that material is the trans polyisoprene is I think they name it Gutta Percha it is a rigid kind of material but this is rubber when it is in the this form which is the cis form that is what is my rubber.

Well there are many more kind of things like this but all of them have different kinds of this linkages can provide by one atom as I have shown with sulphur or it could be provided by some small molecules or small chain so the polymers that is possible and there are different kinds of elastomers they are all like this, so these are the 4 basic characteristics of the chain kind of a polymer which will qualify to be called a elastomer or it will be like an elastomer. Only when it behaves like an elastomer that I call it rubber I did not otherwise call it rubber that is very important.

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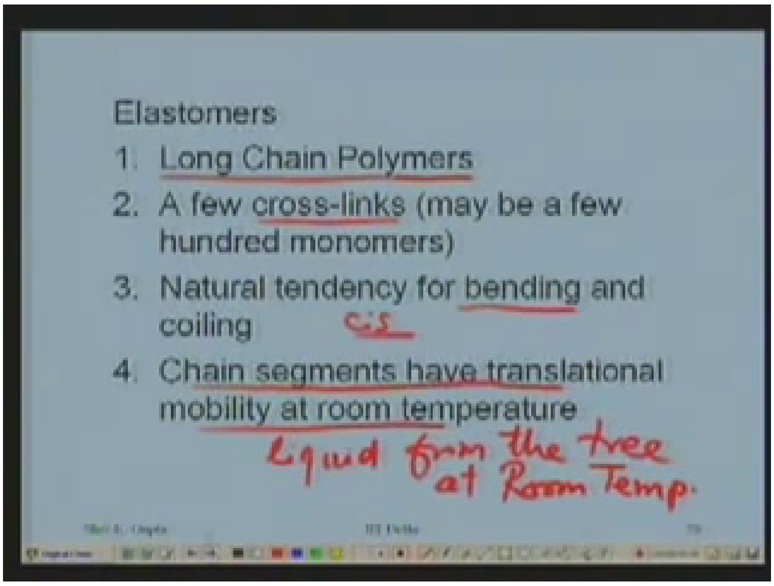

Elastomers

1. Long Chain Polymers
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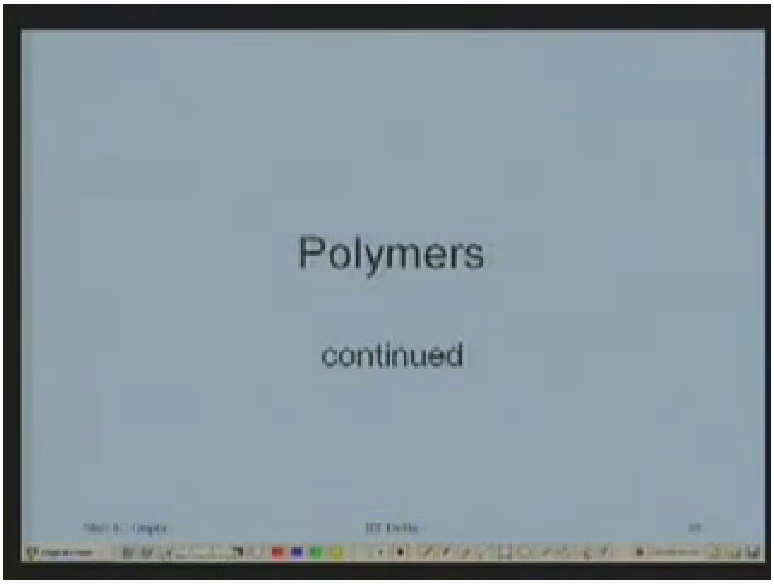
3. Natural tendency for bending and coiling cis
4. Chain segments have translational mobility at room temperature

Liquid from the tree at Room Temp.



Polymers

continued

If I go back to see this, this is important that it is along chain polymer it is not a network polymer. These cross-links are provided as I showed by vulcanisation then there is a natural tendency of bending and coiling because of the cis arrangement (())(53:40) of the same side and it is bigger side so more space and then the chain segments have translation mobility at room temperature that is how it comes out in the form of liquid from the tree at room temperature. So all the 4 conditions are satisfied it to become an elastomer alright. I think we shall not talk about the mechanical behaviour of the elastomer probably in the next class.