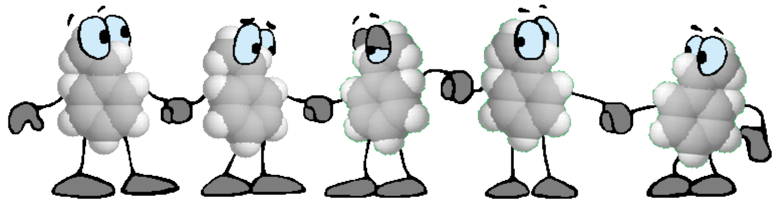
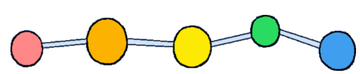
5.

Polimerlerin Sentezi



Polimerleşme
Polimerleşme Çeşitleri
Polimerleşme Mekanizmaları



Polimerleşme

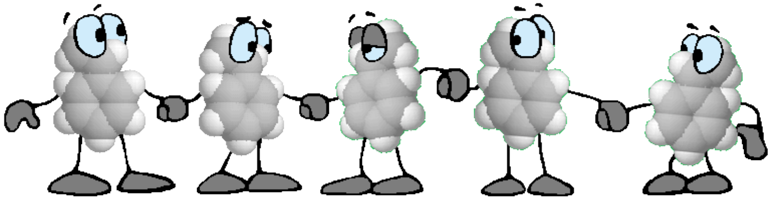
Monomerlerin kimyasal reaksiyonlar sonucu polimerleşebilmeleridir.

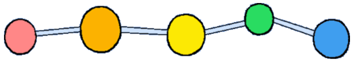
2 basit polimerleşme türü vardır.

1- Basamaklı Reaksiyon (Kondenzasyon Reaksiyonu)
(Step Growth Polimerization)

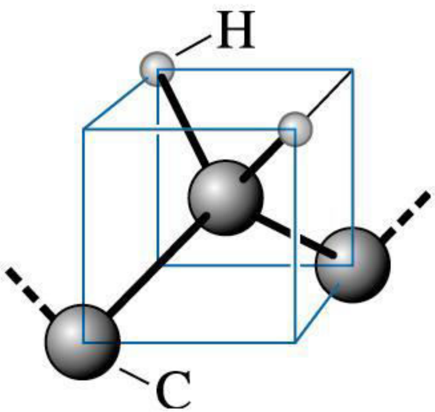
2-Zincir Polimerizasyonu(Katılma Reaksiyonu)

Katyonik Polimerizasyon,
Anyonik Polimerizasyon,
Radikal Polimerizasyon

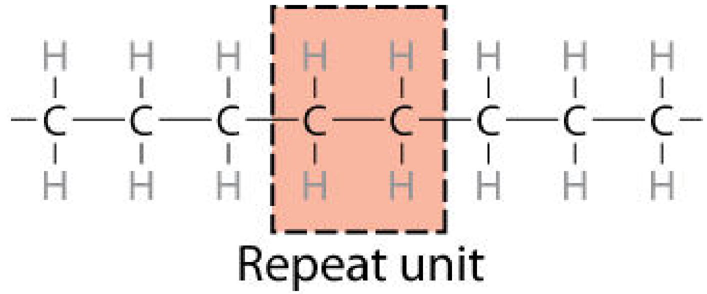


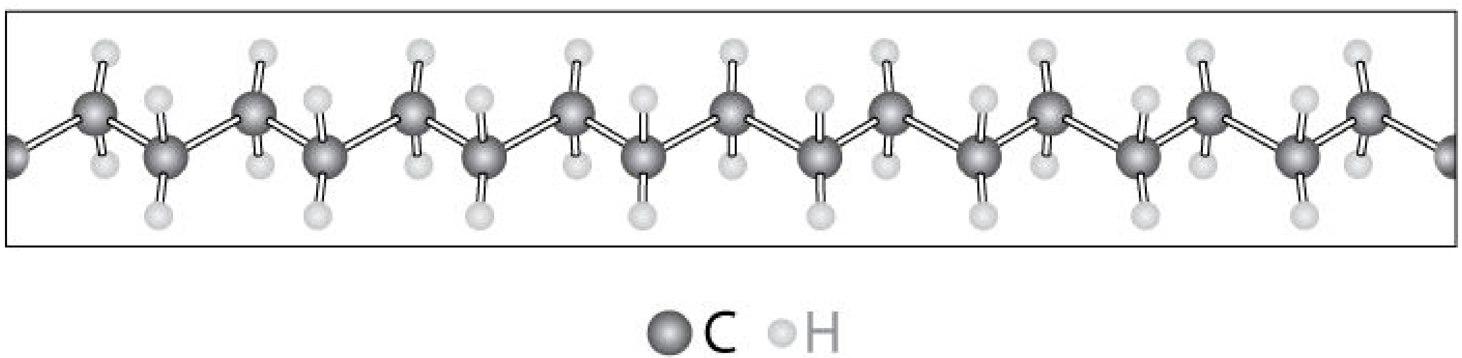


Polietilen Yapısı



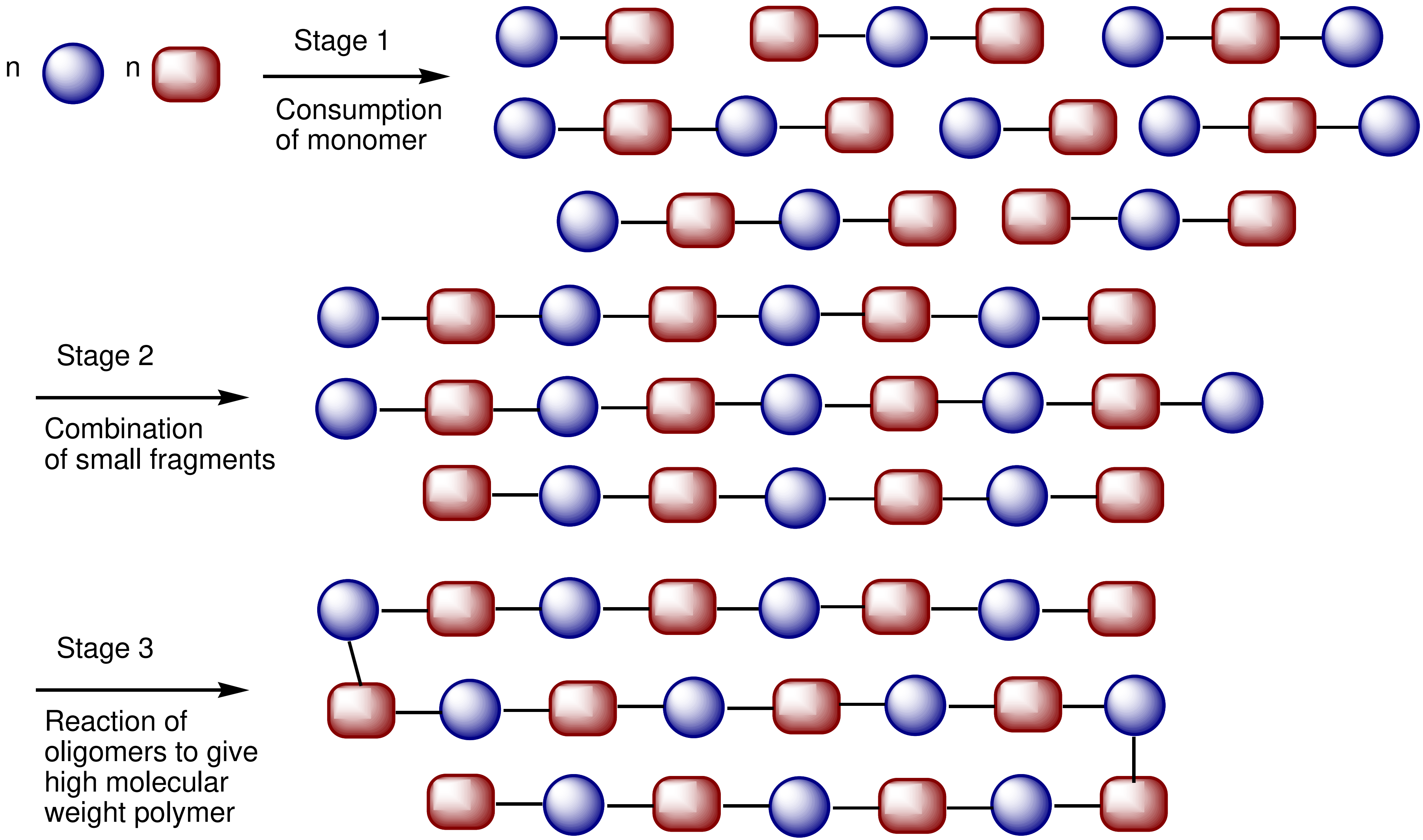
Tetrahedral arrangement of C-H

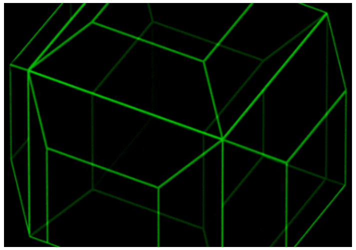


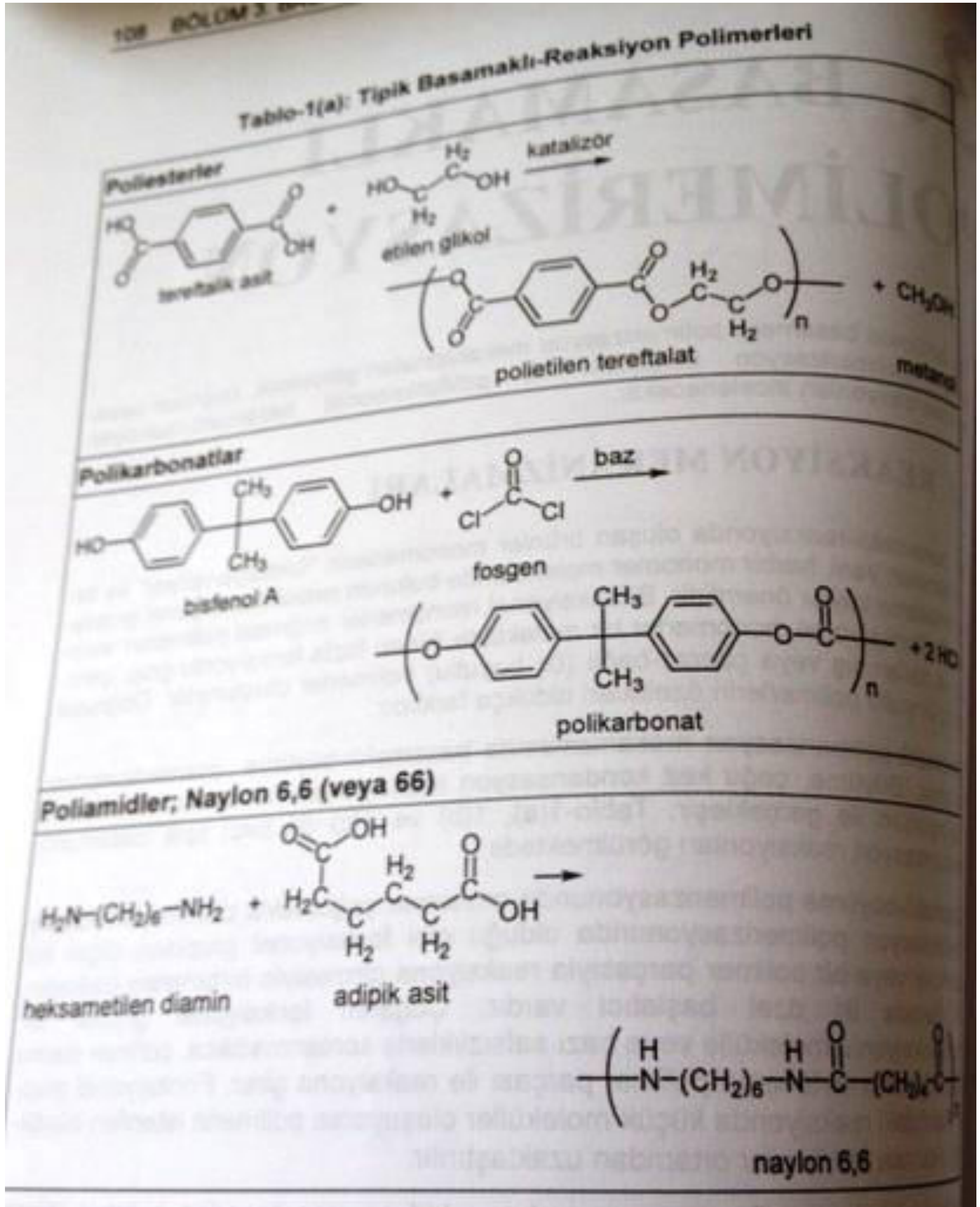


- Polyethylene is a long-chain hydrocarbon.
- Top figure shows repeat unit and chain structures.
- Other figure shows zigzag backbone structure.

Basamaklı Reaksiyon

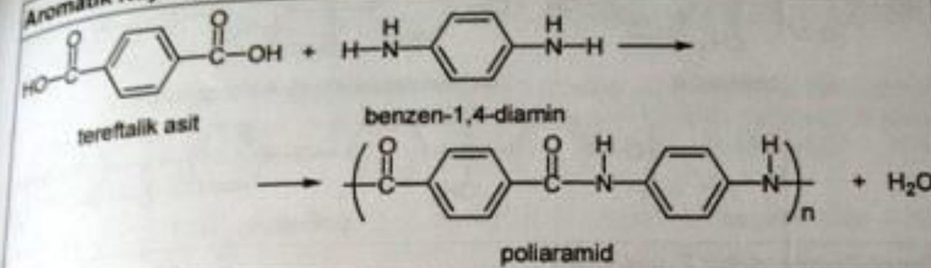




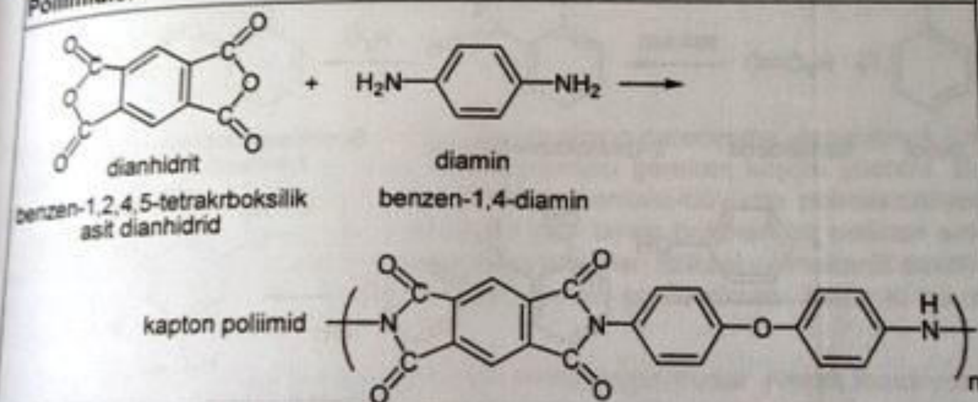

Tablo-1(a): Tipik Basamaklı-Reaksiyon Polimerleri
Poliesterler
katalizor
tereftalik asit
etilen glikol
polietilen tereftalat
Polikarbonatlar
baz
bisfenol A
fosgen
polikarbonat
Poliamidler; Naylon 6,6 (veya 66)
$H_2N-(CH_2)_6-NH_2$
heksametilen diamin
adipik asit
naylon 6,6

Tablo-1(b): Tipik Basamaklı-Reaksiyon Polimerleri

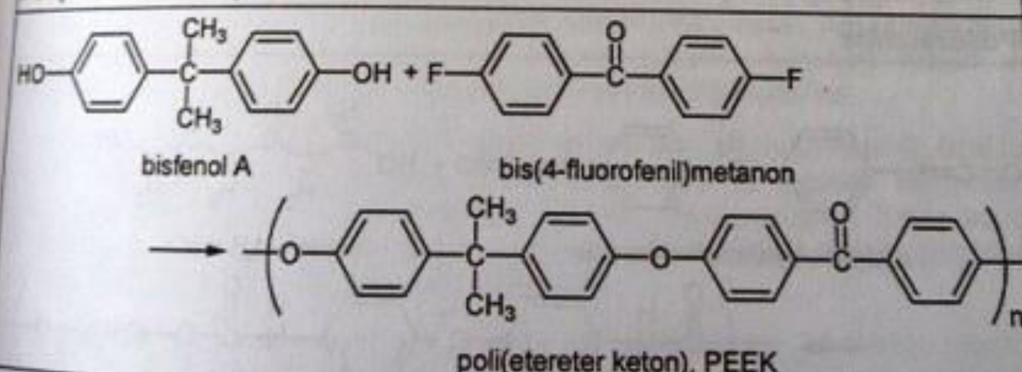
Aromatik Naylonlar

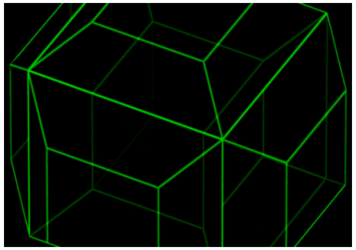


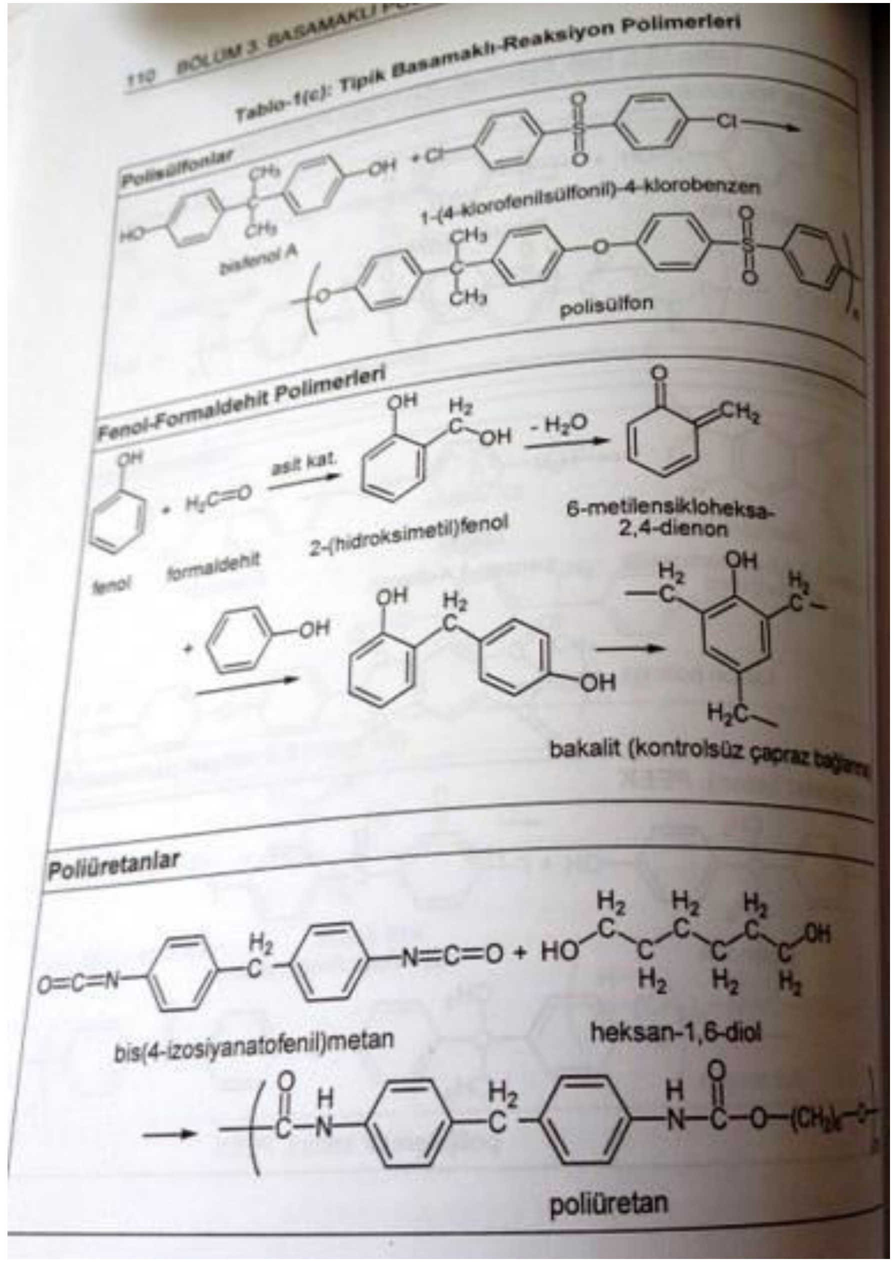
Poliimidler



Poli(etereter keton), PEEK





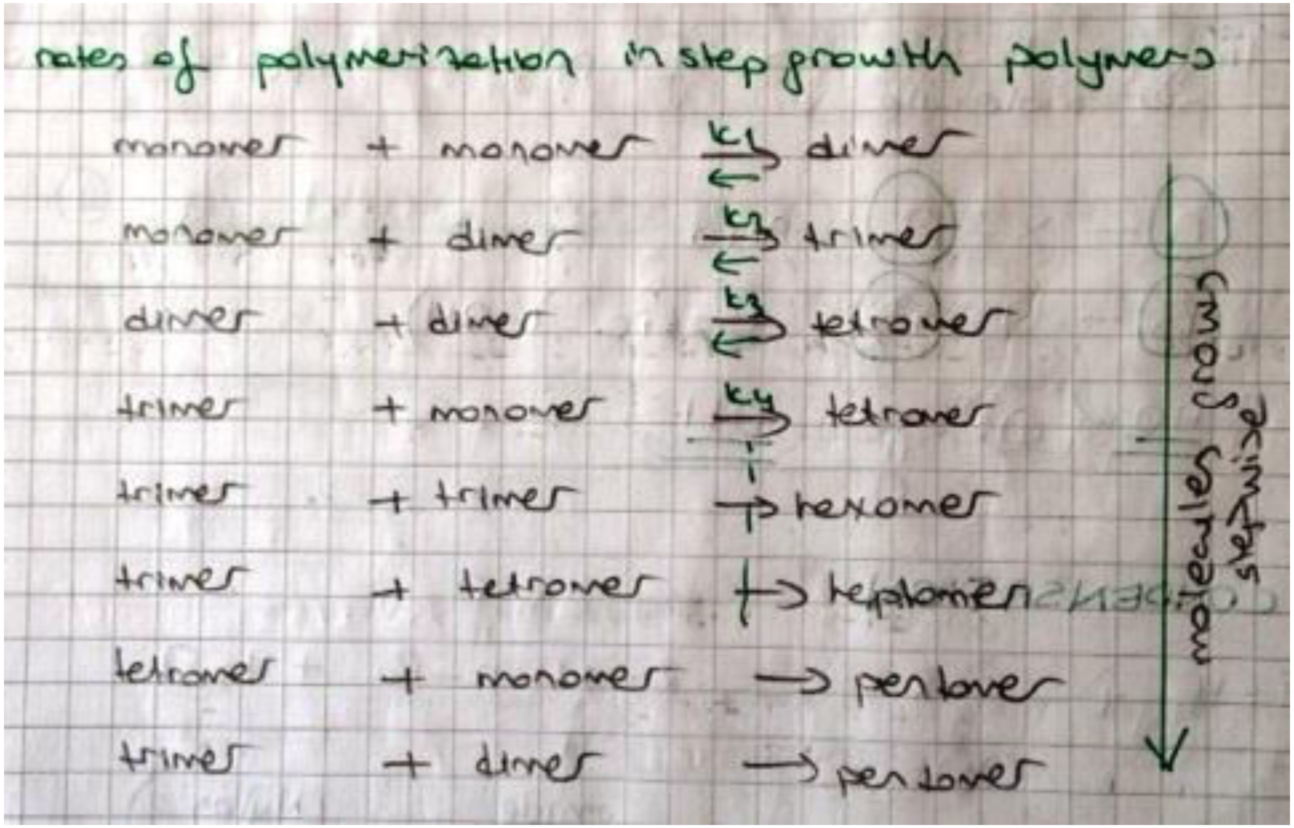


Tablo-1(c): Tipik Basamaklı-Reaksiyon Polimerleri

Polisülfonlar

Fenol-Formaldehit Polimerleri

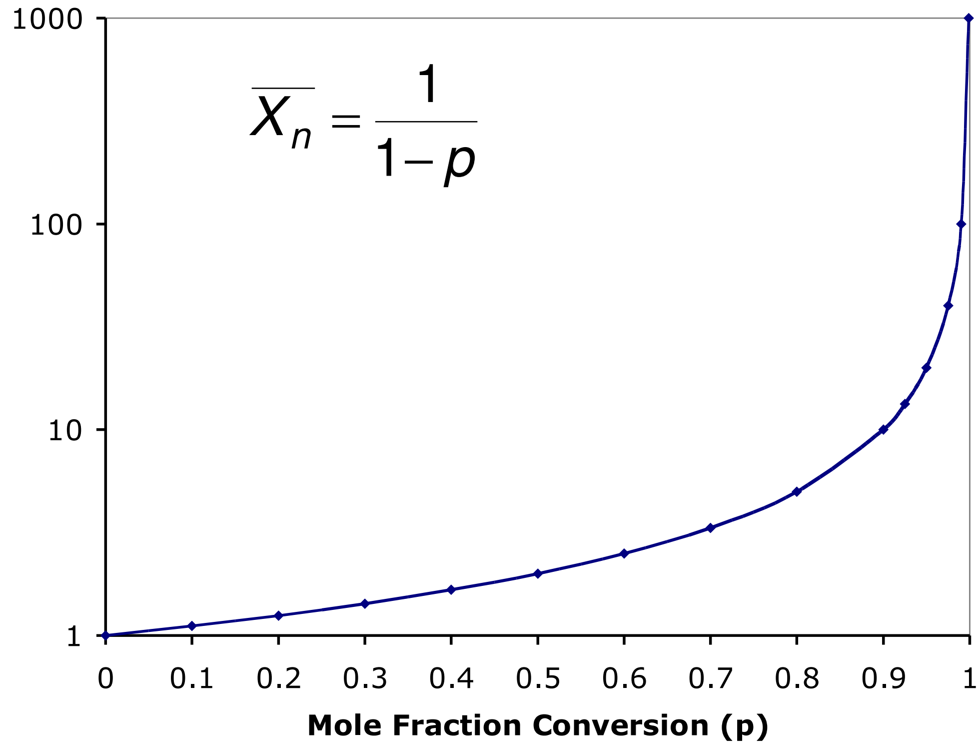
Poliüretanlar


rates of polymerization in step growth polymers
monomer + monomer $\underset{\leftarrow}{\xrightarrow{k_1}}$ dimer
monomer + dimer $\underset{\leftarrow}{\xrightarrow{k_2}}$ trimer
dimer + dimer $\underset{\leftarrow}{\xrightarrow{k_3}}$ tetramer
trimer + monomer $\xrightarrow{k_4}$ tetramer
trimer + trimer → hexomer
trimer + tetramer → heptomer
tetramer + monomer → pentomer
trimer + dimer → pentomer
molecules grows stepwise

Kondenzasyon Reaksiyonu

- Bu tip polimerizasyonda moleküllerin birleşmesi yavaştır. Yüksek molekül ağırlığına ulaşmak üçün uzun zaman gereklidir. Yüksek molekül ağırlıklı malzeme elde edebilmek için her bölgedeki ürünün birleşmesi gereklidir. Tüm polimerizasyon reaksiyonlarında Xn veya DPn ve reaksiyon dönüşümü p arasında doğrusal bir bağlantı vardır.

$$\overline{X_n} = \frac{1}{1-p}$$



X_n = Degree of polymerization
p = mole fraction monomer conversion

X_n = average chainlenght (# of repeating units in the chain)

p = extent of reaction fraction of function groups reached

if p=1 => reaction completed

p=0 => no functional groups

* A – X – B type of monomer

N_0 molecules at t=0

at $t = t_1$

$$\boxed{P = \frac{N_0 - N_1}{N_0}}$$

N=1 N_0=10

if $N \cong 0$ => The reaction completed

$$p = \frac{N_0}{N_0} = 1$$

$$\boxed{X_n = \frac{N_0}{N}} \qquad P = \frac{N_0 - N}{N_0} \qquad 1 - \frac{N}{N_0} = P$$

$$1 - P = \frac{N}{N_0}$$

$$\boxed{X_n = \frac{1}{1-P}} \qquad \boxed{(X_n) \cdot M_0 = \bar{M}_n}$$

m_0 = repeating unit's molecular weight

The values are for caprolactam

p = 0.9	X_n = 10	M_N = 1310 g/mol
p = 0.95	X_n = 50	M_N = 6550 g/mol
p = 0.99	X_n = 100	M_N = 13100 g/mol
p = 0.999	X_n = 1000	M_N = 131000 g/mol

→ polymer

To be a polymer, it should be over 100 monomers.

- Bazen reaksiyonların çok yüksek molekül ağırlığı ile gitmesini, istemeyiz. Çünkü proses etmek zorlaşır. O zaman Endüstri de molekül ağırlığını kontrol altında tutmak gerekir.

- Molekül ağırlığını kontrol etmek için bazı metotlar kullanılır.

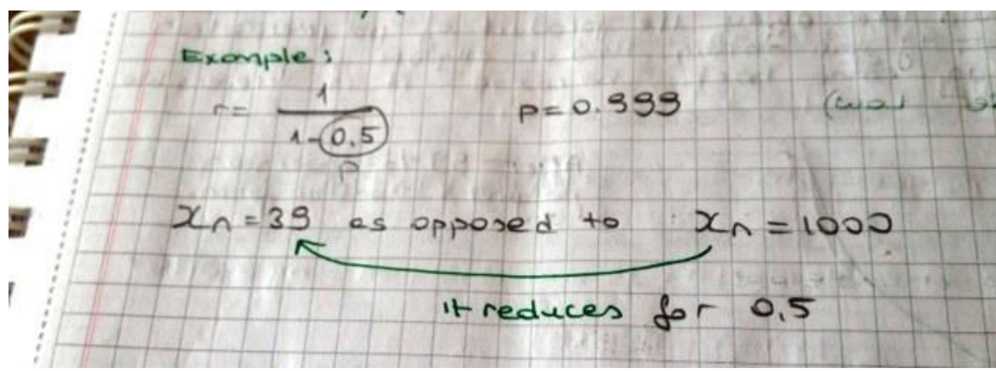
1. Nonstokiyometrik başlangıç konsantrasyonları kullanmak

A-X-A (No+0.01) mol / L
B-Y-B (No) mol / L

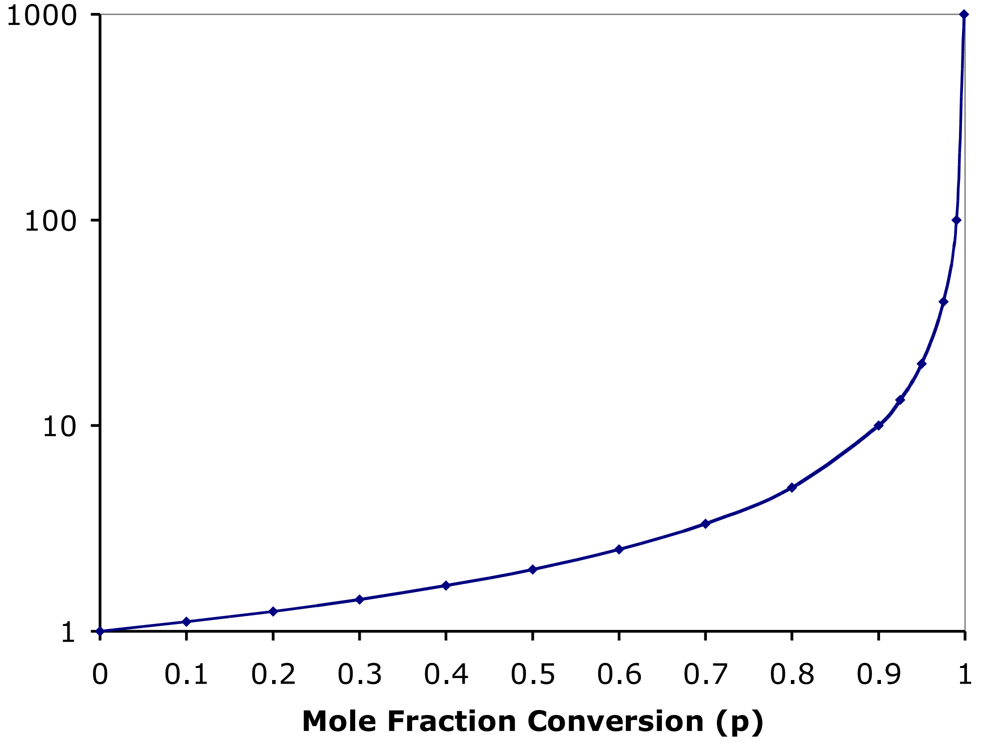
r= No / No+0.01 $\Rightarrow$ r < 1

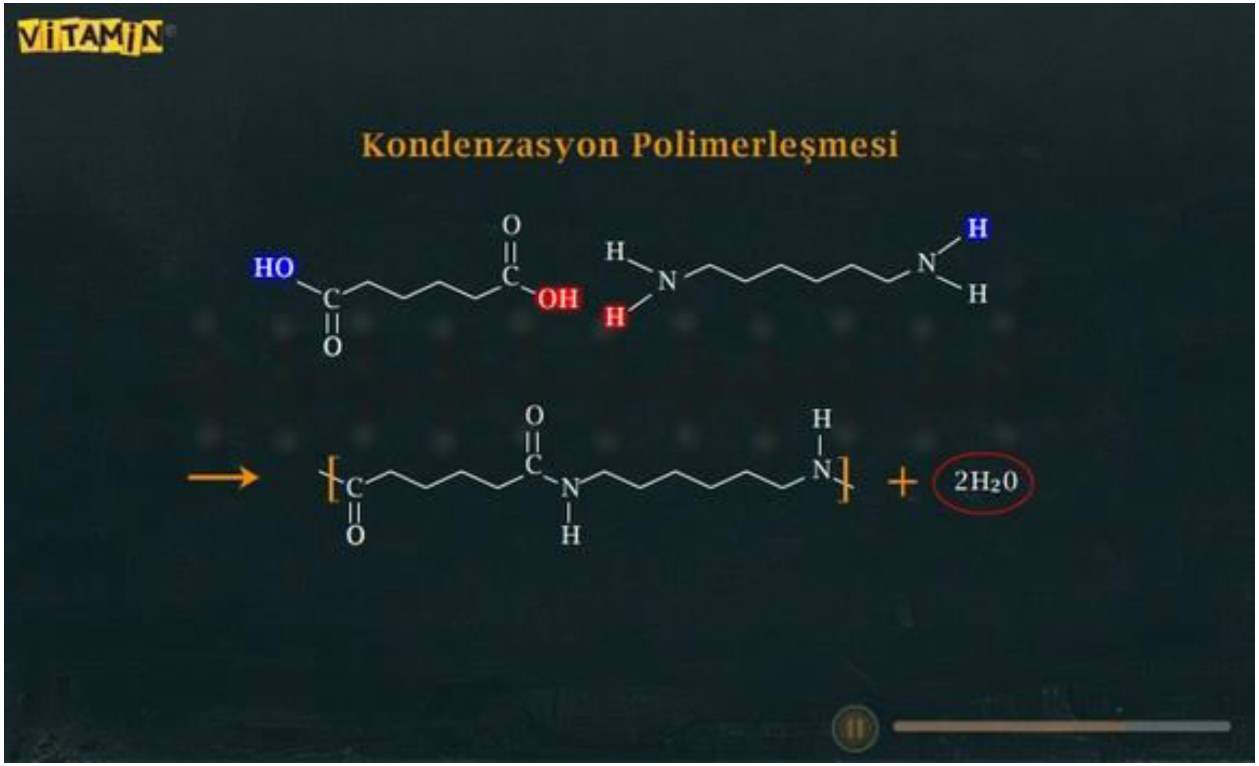
Nonstokiyometrik
Xn = 1+r / 1+r-2rp r≠ 1

Stokiyometrik
Xn = 1/1-p



- Monofonksiyonel gruplar reaksiyon ortamına koyarak eklenerek polimerleşmeyi kontrol altında tutabiliriz

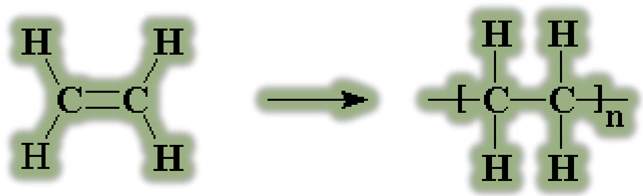




Le Chatelier İlkesine göre, kimyada dengedeki bir sisteme dışarıdan bir etkide bulunulduğunda, sistem bu etkiyi azaltıcı yönde yeni bir denge hali oluşturur.

Katılma Polimerizasyonu : **Eğer kullanılan tüm monomer molekülü polimerin bir parçası haline geliyorsa bu tür polimerizasyona katılma polimerizasyonu denir.**
Kondenzasyon Polimerizasyonu : **Eğer monomerin bir parçası polimerin yapısında bulunuyorsa buna da kondenzasyon polimerizasyonu denir. Reaksiyon sonrası ayrılan parça genellikle su, HCl gibi küçük moleküllerdir.**

Mesela eilen molekül polimerleştiğinde Polietilen adını alır ve etilen molekülünün her bir atomu polimer yapısı içinde vardır. Monomer polimere tam anlamıyla katılmıştır.

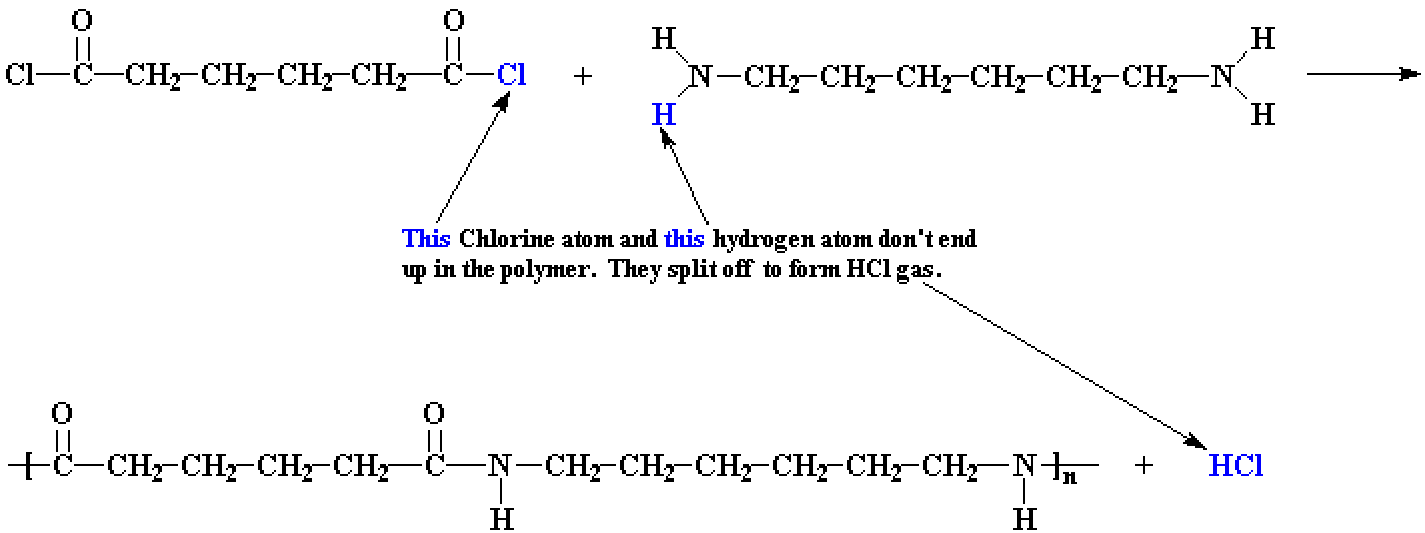


Ethylene has two carbon atoms and four hydrogen atoms, and the polyethylene repeat structure has two carbon atoms and four hydrogen atoms. None gained, none lost.

Some Common Addition Polymers

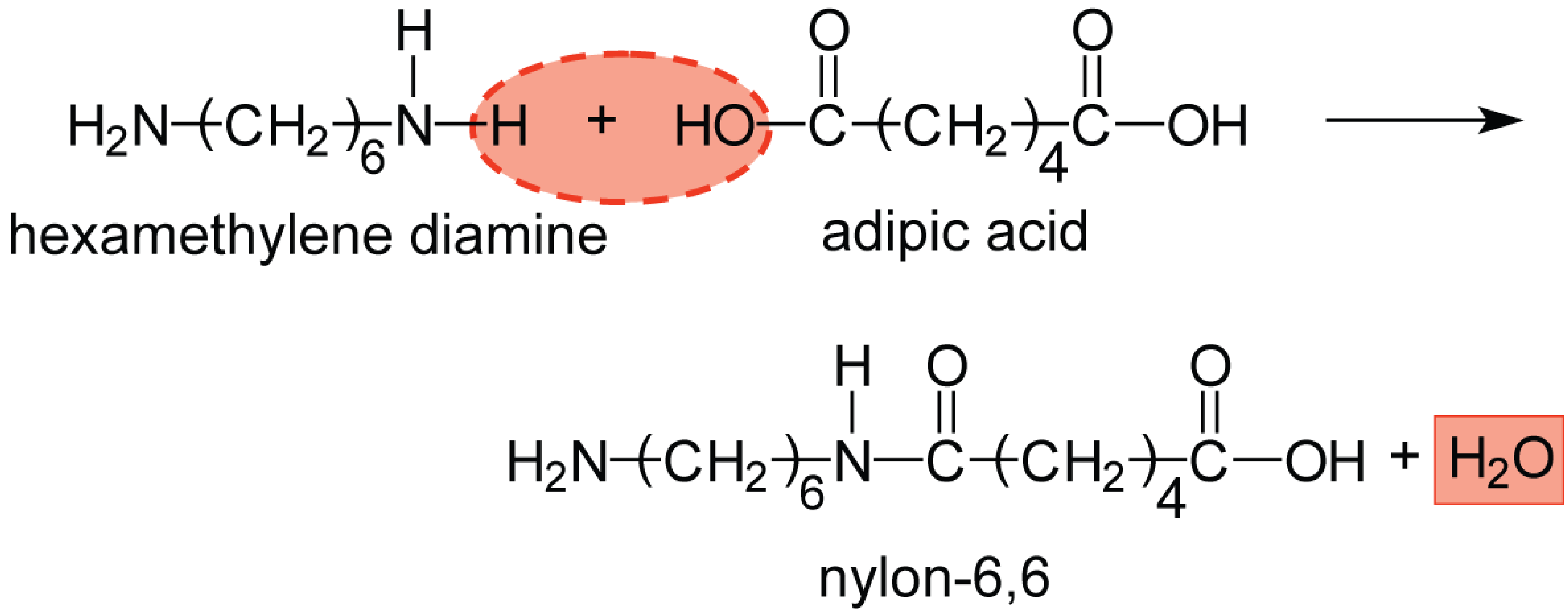
Name(s)	Formula	Monomer	Properties	Uses
Polyethylene low density (LDPE)	$–(CH_2\text{-}CH_2)_n–$	ethylene $CH_2=CH_2$	soft, waxy solid	film wrap, plastic bags
Polyethylene high density (HDPE)	$–(CH_2\text{-}CH_2)_n–$	ethylene $CH_2=CH_2$	rigid, translucent solid	electrical insulation bottles, toys
Polypropylene (PP) different grades	$–[CH_2\text{-}CH(CH_3)]_n–$	propylene $CH_2=CHCH_3$	atactic: soft, elastic solid isotactic: hard, strong solid	similar to LDPE carpet, upholstery
Poly(vinyl chloride) (PVC)	$–(CH_2\text{-}CHCl)_n–$	vinyl chloride $CH_2=CHCl$	strong rigid solid	pipes, siding, flooring
Poly(vinylidene chloride) (Saran A)	$–(CH_2\text{-}CCl_2)_n–$	vinylidene chloride $CH_2=CCl_2$	dense, high-melting solid	seat covers, films
Polystyrene (PS)	$–[CH_2\text{-}CH(C_6H_5)]_n–$	styrene $CH_2=CHC_6H_5$	hard, rigid, clear solid soluble in organic solvents	toys, cabinets packaging (foamed)
Polyacrylonitrile (PAN, Orlon, Acrilan)	$–(CH_2\text{-}CHCN)_n–$	acrylonitrile $CH_2=CHCN$	high-melting solid soluble in organic solvents	rugs, blankets clothing
Polytetrafluoroethylene (PTFE, Teflon)	$–(CF_2\text{-}CF_2)_n–$	tetrafluoroethylene $CF_2=CF_2$	resistant, smooth solid	non-stick surfaces electrical insulation
Poly(methyl methacrylate) (PMMA, Lucite, Plexiglas)	$–[CH_2\text{-}C(CH_3)CO_2CH_3]_n–$	methyl methacrylate $CH_2=C(CH_3)CO_2CH_3$	hard, transparent solid	lighting covers, signs skylights
Poly(vinyl acetate) (PVAc)	$–(CH_2\text{-}CHOCOCH_3)_n–$	vinyl acetate $CH_2=CHOCOCH_3$	soft, sticky solid	latex paints, adhesives
cis-Polyisoprene natural rubber	$–[CH_2\text{-}CH=C(CH_3)\text{-}CH_2]_n–$	isoprene $CH_2=CH\text{-}C(CH_3)=CH_2$	soft, sticky solid	requires vulcanization for practical use
Polychloroprene (cis + trans) (Neoprene)	$–[CH_2\text{-}CH=CCl\text{-}CH_2]_n–$	chloroprene $CH_2=CH\text{-}CCl=CH_2$	tough, rubbery solid	synthetic rubber oil resistant

Kondenzasyon Polimerizasyonu : Nylon 6,6

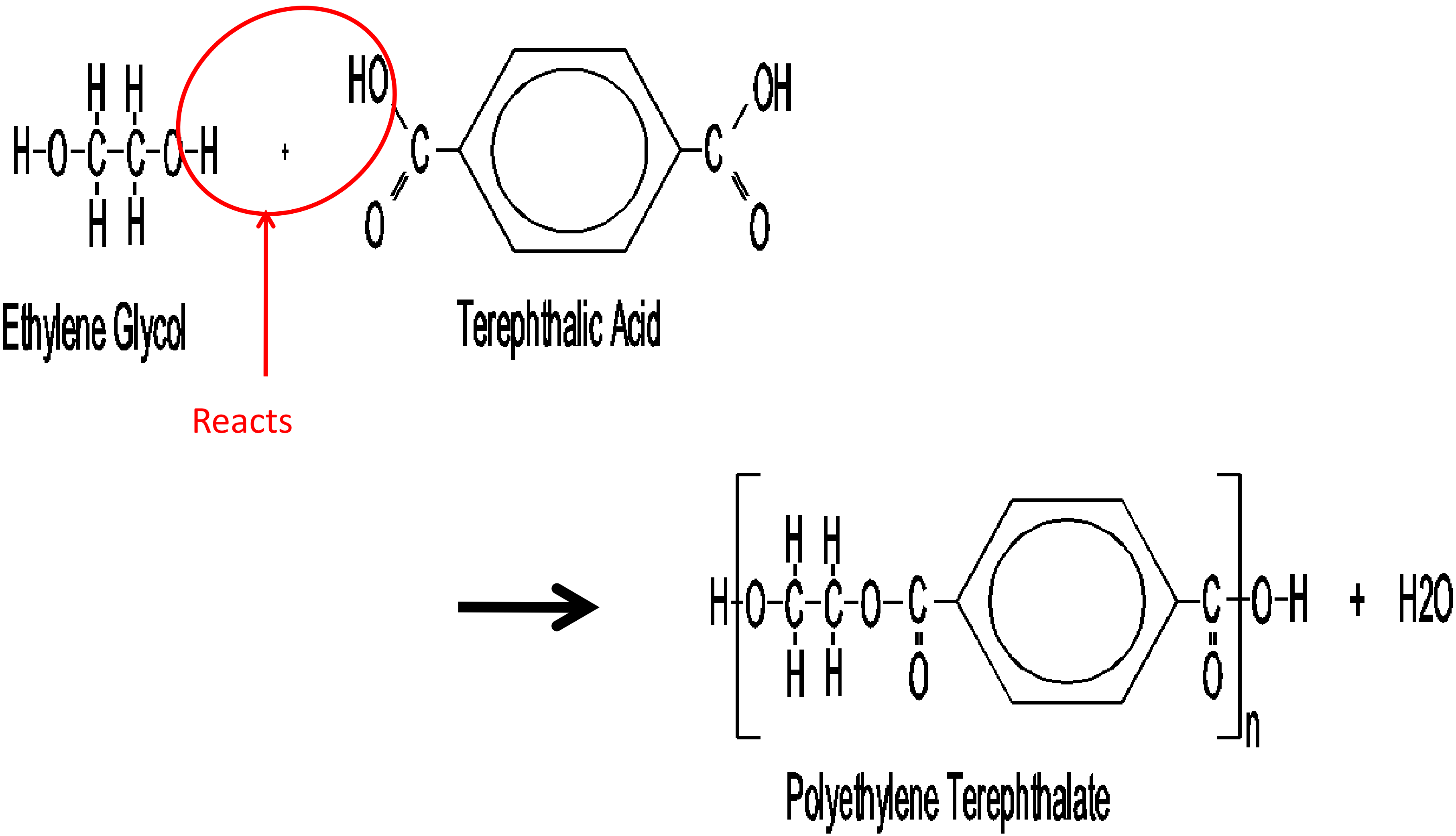


Original monomerler polimer yapısını oluşturacak bir araya gelip tartılsa polimerden daha fazla olduğu gözlemlenir. Bu durumda monomerlerin yapısının bir kısmı polimer yapısını oluştururken kondenze olmuştur ve yan ürün olarak farklı yapılar açığa çıkmıştır.

Condensation (Step) Polymerization



Example: Condensation Reactions



PET

Condensation Polymerization (Examples include: nylons, polyesters, urethanes, natural rubber)

Condensation polymerization – chemical reaction produces new polymer!

1. Thermoplastic, or
2. Thermoset (chemical bond attaches molecules together) can not be remelted or recycled Ex: Most elastomers (natural rubber, butyl, neoprene, silicone, etc.)

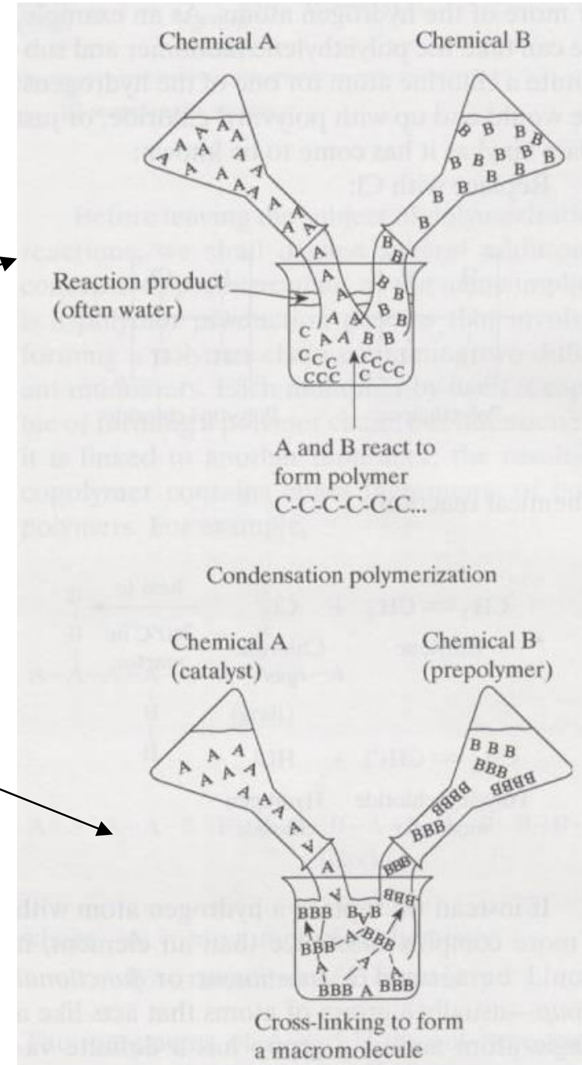
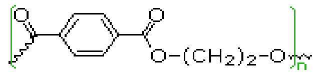
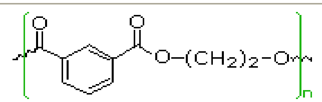
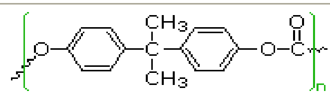
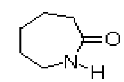
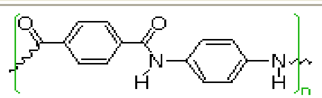
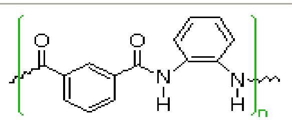
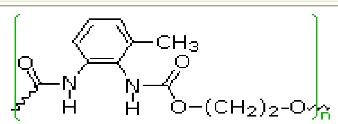
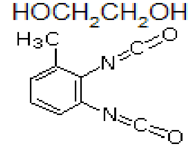


Figure 4–2
Polymerization reactions

Some Condensation Polymers

Formula	Type	Components	T_g °C	T_m °C
~$[CO(CH_2)_4CO\text{-}OCH_2CH_2O]_n$~	**polyester**	$HO_2C\text{-}(CH_2)_4\text{-}CO_2H$ $HO\text{-}CH_2CH_2\text{-}OH$	< 0	50
	**polyester** Dacron Mylar	para $HO_2C\text{-}C_6H_4\text{-}CO_2H$ $HO\text{-}CH_2CH_2\text{-}OH$	70	265
	**polyester**	meta $HO_2C\text{-}C_6H_4\text{-}CO_2H$ $HO\text{-}CH_2CH_2\text{-}OH$	50	240
	**polycarbonate** Lexan	$(HO\text{-}C_6H_4\text{-})_2C(CH_3)_2$ (Bisphenol A) $X_2C{=}O$ ($X = OCH_3$ or Cl)	150	267
~$[CO(CH_2)_4CO\text{-}NH(CH_2)_6NH]_n$~	**polyamide** Nylon 66	$HO_2C\text{-}(CH_2)_4\text{-}CO_2H$ $H_2N\text{-}(CH_2)_6\text{-}NH_2$	45	265
~$[CO(CH_2)_5NH]_n$~	**polyamide** Nylon 6 Perlon		53	223
	**polyamide** Kevlar	para $HO_2C\text{-}C_6H_4\text{-}CO_2H$ para $H_2N\text{-}C_6H_4\text{-}NH_2$	---	500
	**polyamide** Nomex	meta $HO_2C\text{-}C_6H_4\text{-}CO_2H$ meta $H_2N\text{-}C_6H_4\text{-}NH_2$	273	390
	**polyurethane** Spandex	$HOCH_2CH_2OH$ 	52	---

Kinetic of Condensation Polymerization

$$A \sim A \longrightarrow \text{Polymerization}$$

First order

$$A \sim A + B \sim B \longrightarrow \text{Polymerization}$$

Second order

if elementary

$$A \sim A + B \sim B \xrightarrow{\text{catalyst}} \text{Polymerization}$$

Third order

- Equivalent reactivity of functional groups.
- It may be first, second or third order by depending upon.

http://www.materialsworldmodules.org/resources/polimarization/4-condensation.html

Kinetic of Condensation Polymerization

$$R_o = -\frac{d[A\sim A]}{dt} = k\,[A\sim A][B\sim B]$$

- Assumption = a stoichiometry balance of monomer concentration

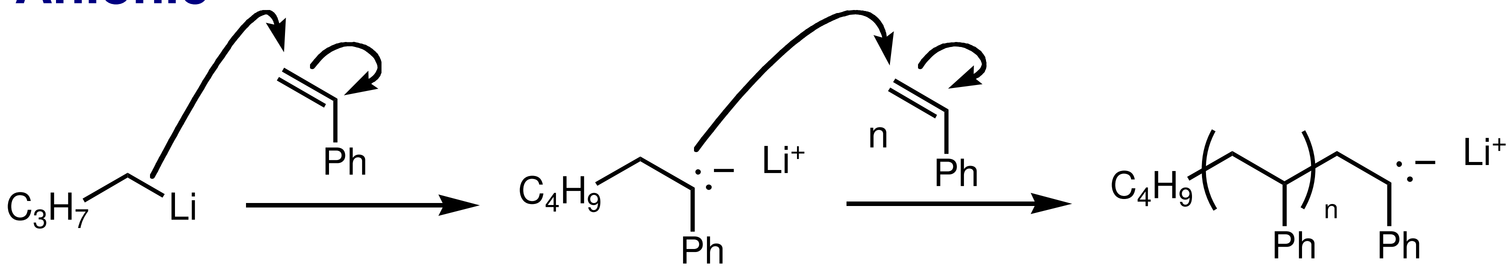
$$-\frac{d[A\sim A]}{dt} = k\,[A\sim A]^2$$

$$\overline{X_n} = [A\sim A]_0\,kt + 1$$

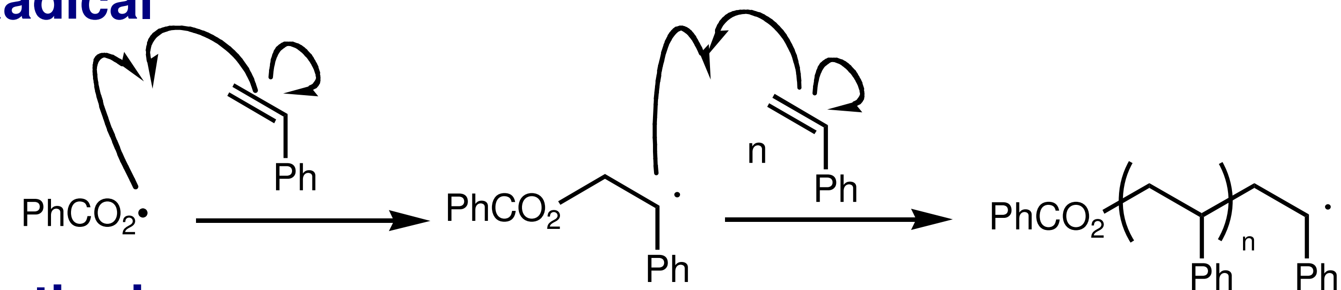
http://www.materialsworldmodules.org/resources/polimarization/4-condensation.html

Katılma Polimerizasyon Çeşitleri

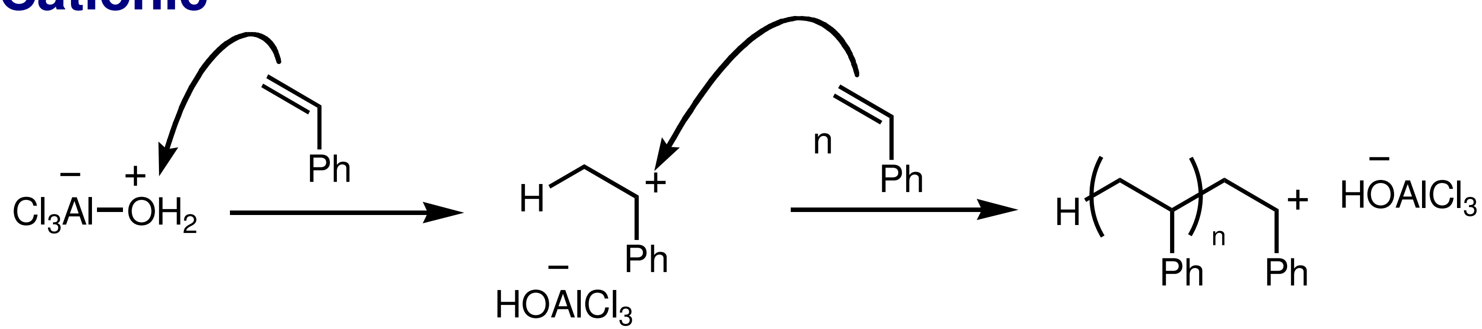
Anionic



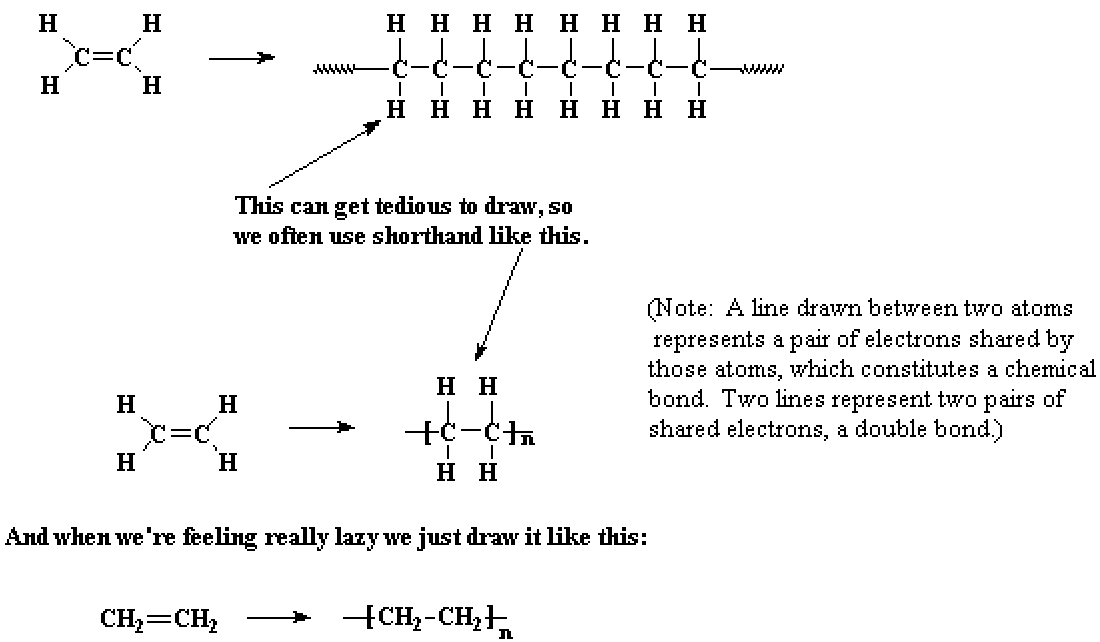
Radical



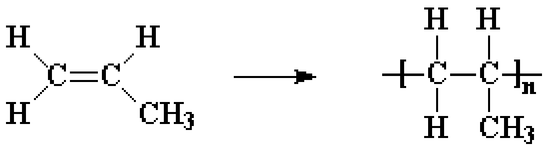
Cationic



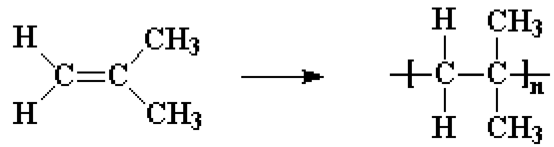
Vinil polimerler vinil monomerlerden oluşturulan polimelerdir. Vinil monomerleri karbon karbon bağları arasında çifte bağ taşıyan yapılardır. Polimerleşme sırasında monomerler bu çift bağların birinin açılması ile polimerleşmeye gider.



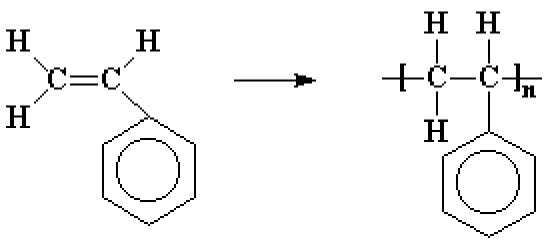
polypropylene



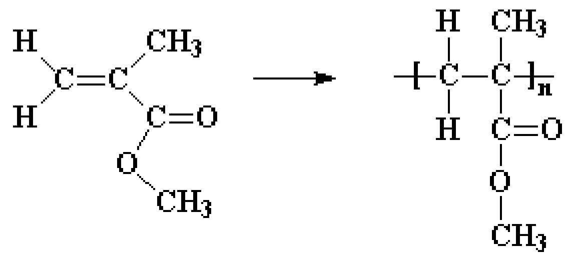
polyisobutylene



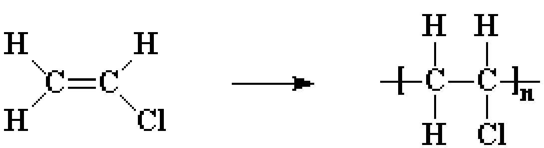
Polystyrene



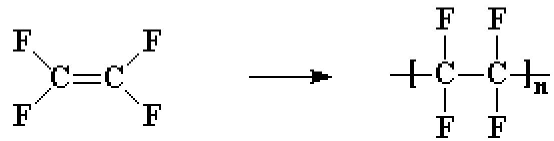
poly(methyl methacrylate)



poly(vinyl chloride)



polytetrafluoroethylene,



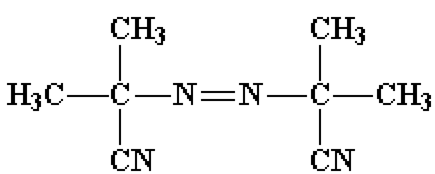
Vinyl polymers are made from vinyl monomers in a variety of ways, like:

- free radical vinyl polymerization
- anionic vinyl polymerization
- cationic vinyl polymerization
- Ziegler-Natta catalysis
- metallocene catalysis polymerization

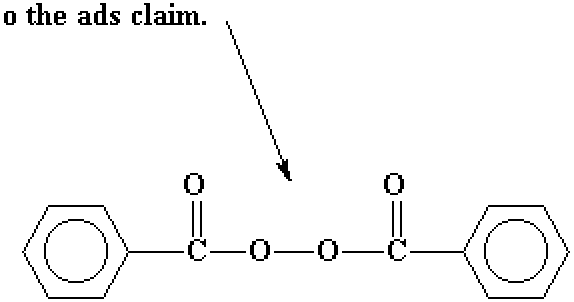
Polimerlerin sentezi sırasında en çok kullanılan polimerizasyon çeşidi Free Radikal Vinil polimerizasyonu dur.

polystyrene
poly(methyl methacrylate),
poly(vinyl acetate)
branched polyethylene.

This is the same benzoyl peroxide that rids teenage faces of zits and transforms angst-ridden adolescents into popular, happy, and attractive young citizens, or so the ads claim.

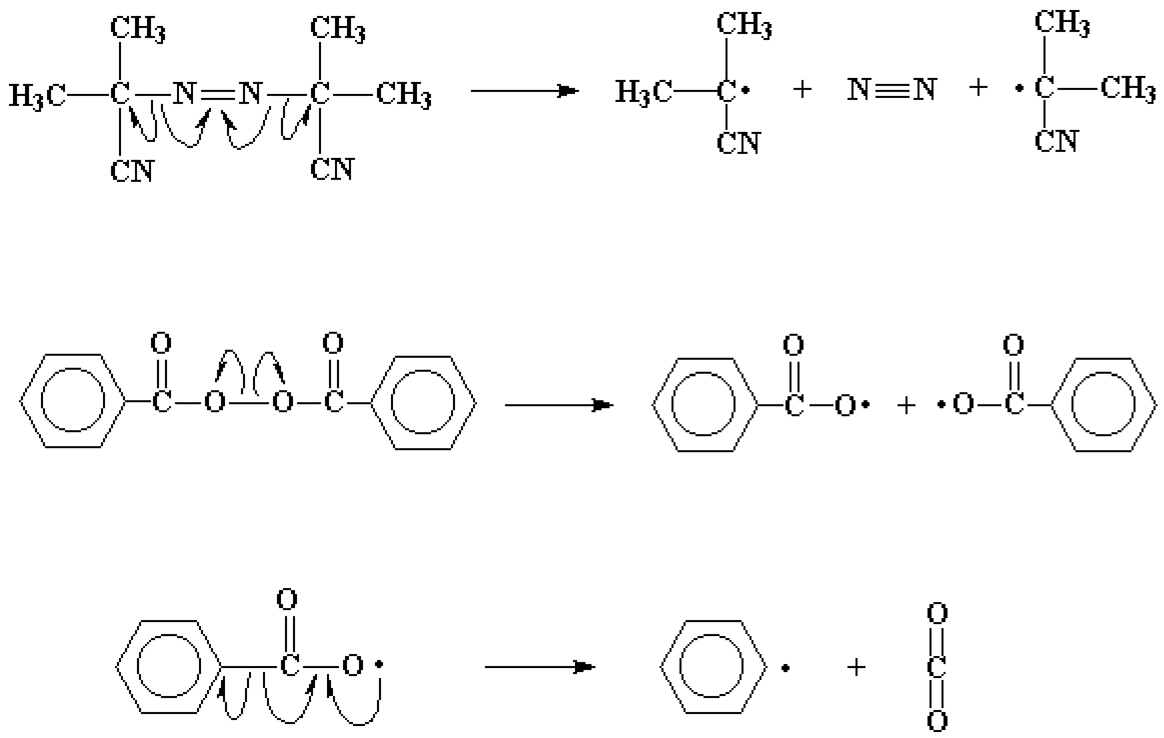


2-2'-azo-*bis*-isobutyrylnitrile
(AIBN)



benzoyl peroxide

Free Radical Vinyl Polymerization



Kinetic of Radicalic Polymerization

Initiation;

$$I \sim I \xrightarrow{k_d} 2\,I\cdot$$

Dissociation

$$I^{\cdot} + M \xrightarrow{k_a} IM\cdot$$

Assosiation

Propagation;

$$IM\cdot + M \xrightarrow{k_p} IMM^{\cdot}$$

$$\vdots$$

$$IM_X\cdot + M \xrightarrow{k_p} IM_XM^{\cdot}$$

Termination;

$$IM_{X\text{-}1}M^{\cdot} + \cdot MM_{Y\text{-}1}I \xrightarrow{k_{tc}} IM_{X\text{-}1}M - MM_{Y\text{-}1}I$$

Combination

$$IM_{X\text{-}1}M + \cdot MM_{Y\text{-}1}I \xrightarrow{k_{td}} IM_X + IM_y$$

Disproportionation

http://www.materialsworldmodules.org/resources/polimarization/4-condensation.html

Kinetic of Radicalic Polymerization

$$k_t = k_{tc} + k_{td}$$

$$R_o = R_p = k_p\,[IM_x \cdot]\,[M]$$

$$R_i = R_t = \frac{d[I\;]}{dt} = 2\,f\,k_d\,[\,I\,]$$

$$R_t = -\frac{d[IM_x\;]}{dt} = 2\;k_t\,[\,IM_x \cdot]^2$$

$$[\,I\,] = [\,I\,]_0\;e^{-kd.t}$$

- R_o = overall rate of polimerization
- R_p = rate of chain propagation
- R_i = rate of initiation step
- R_t = rate of termination step

http://www.materialsworldmodules.org/resources/polimarization/4-condensation.html

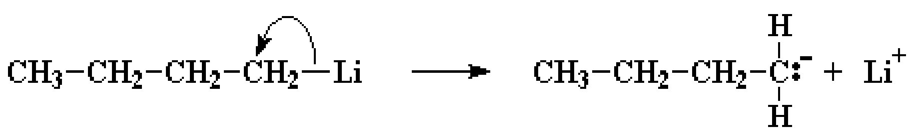
Anyonik polimerizasyonda proses genellikle bir başlatıcı ile başlar. Bu sefer başlatıcı bir anyondur ve negatif elektrik yükü ile kaplıdır.

Anyonik vinil polimerizasyonunda kullanılan bir çok başlatıcı vardır fakat en çok kullanılan bütil lityumdur.

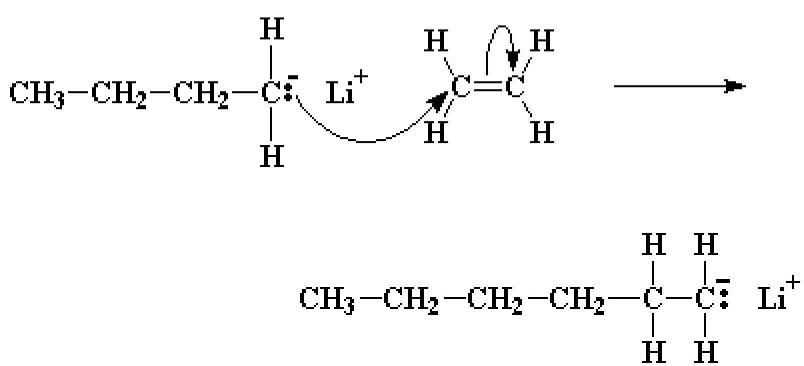
$$CH_3-CH_2-CH_2-CH_2-Li$$

butyl lithium

carbanion : karbanyon oluşumu

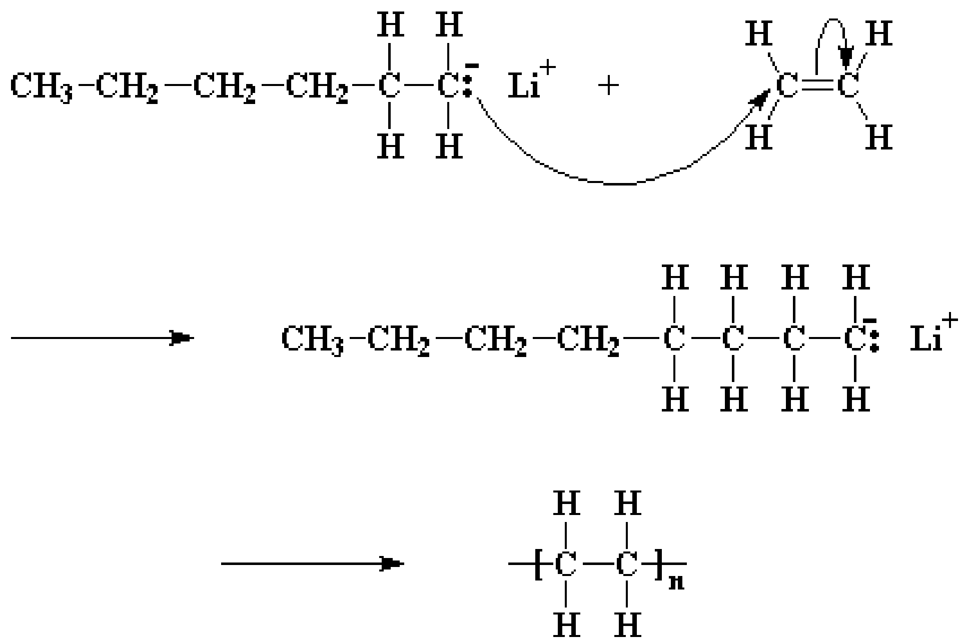


Bütil anyonundan bir çift elektron monomerin karbon atomunun çifte bağından birine saldırır. Bu başlatma basamağı dır.



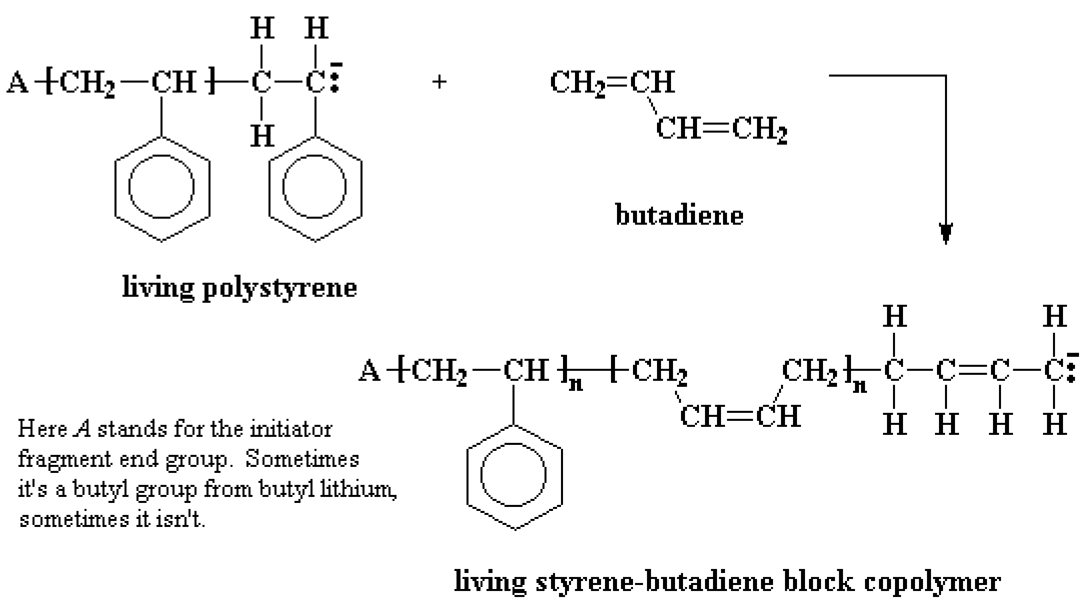
Anionic Vinyl Polymerization

Çoğalma Basamağı



The Chain That Wouldn't Die

Now while you may get this nagging feeling that this can't go on forever, that something has to put a stop to this convenient process. Funny thing, though: it doesn't stop! In many cases, the only thing that stops monomers from adding to the growing chain, is that eventually there are no more monomer molecules in the beaker left to add! And even then, if someone came along some time later and dumped *more* monomer into the beaker, they would add to the chain and the chain would grow some more! Some chains of polystyrene have been known to stay active like this for years. In order to stop them, something like water, which reacts with the carbanions, has to be added to the polymer. Systems like this are called *living* anionic polymerizations. This allows us to do some interesting tricks…



Anionic Polymerization=Living Polymerization

If the starting reagents are pure and the polimerization reactor is purged of all oxygen and traces of water, polimerization can proceed until all monomer is consumed.

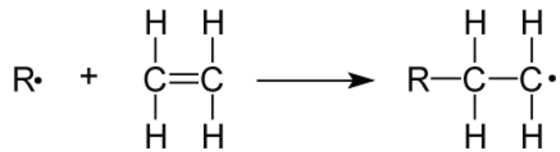
Cationic Vinyl Polymerization

Cationic vinyl polymerization is a way of making polymers from small molecules, or monomers, which contain carbon-carbon double bonds. Its primary commercial use is for making polyisobutylene.

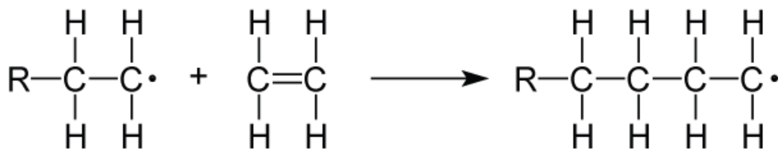
In cationic vinyl polymerization, the initiator is a cation, which is an ion with a positive electrical charge. It is shown as A+ in the picture. A pair of electrons, negatively charged, from the carbon-carbon double bond will be attracted to this cation, and will leave the carbon-carbon double bond to form a single bond with the initiator, as shown. This leaves one of the former double bond carbons at a loss for electrons, and carrying a positive charge. This new cation will react with a second monomer molecule in the same manner as the initiator reacted with the first monomer molecule. This happens over and over until a high molecular weight is reached, that is, a molecular weight at which the polymer is useful for something.

Addition (Chain) Polymerization

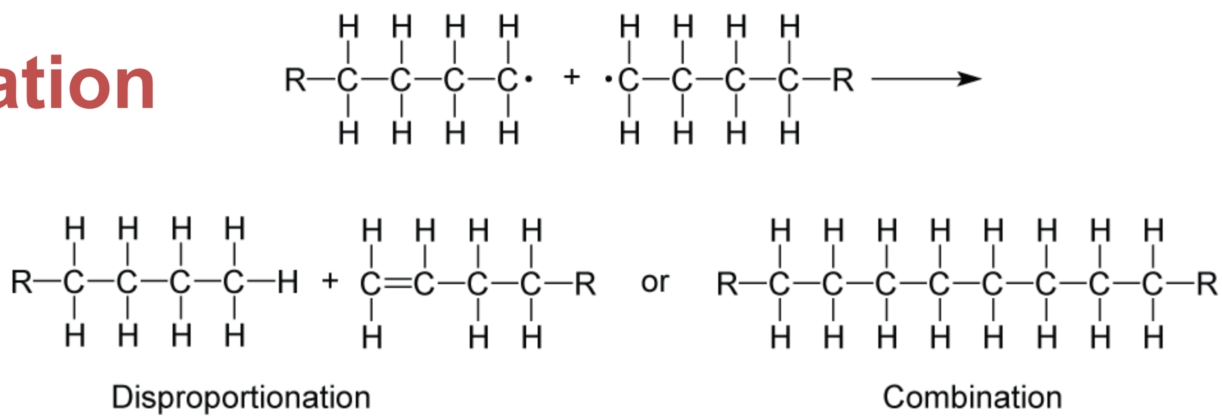
– **Initiation**



– **Propagation**



– **Termination**



Addition Polymerization

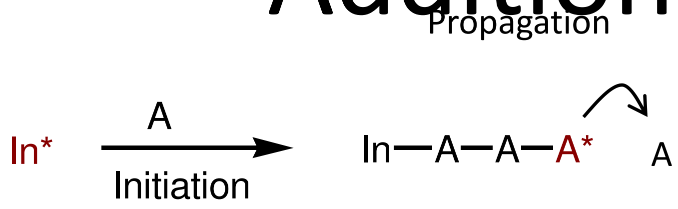
$$\mathrm{In}^* \xrightarrow[\text{Initiation}]{\mathrm{A}} \mathrm{In{-}A}^* \quad \mathrm{A}$$

Addition Polymerization

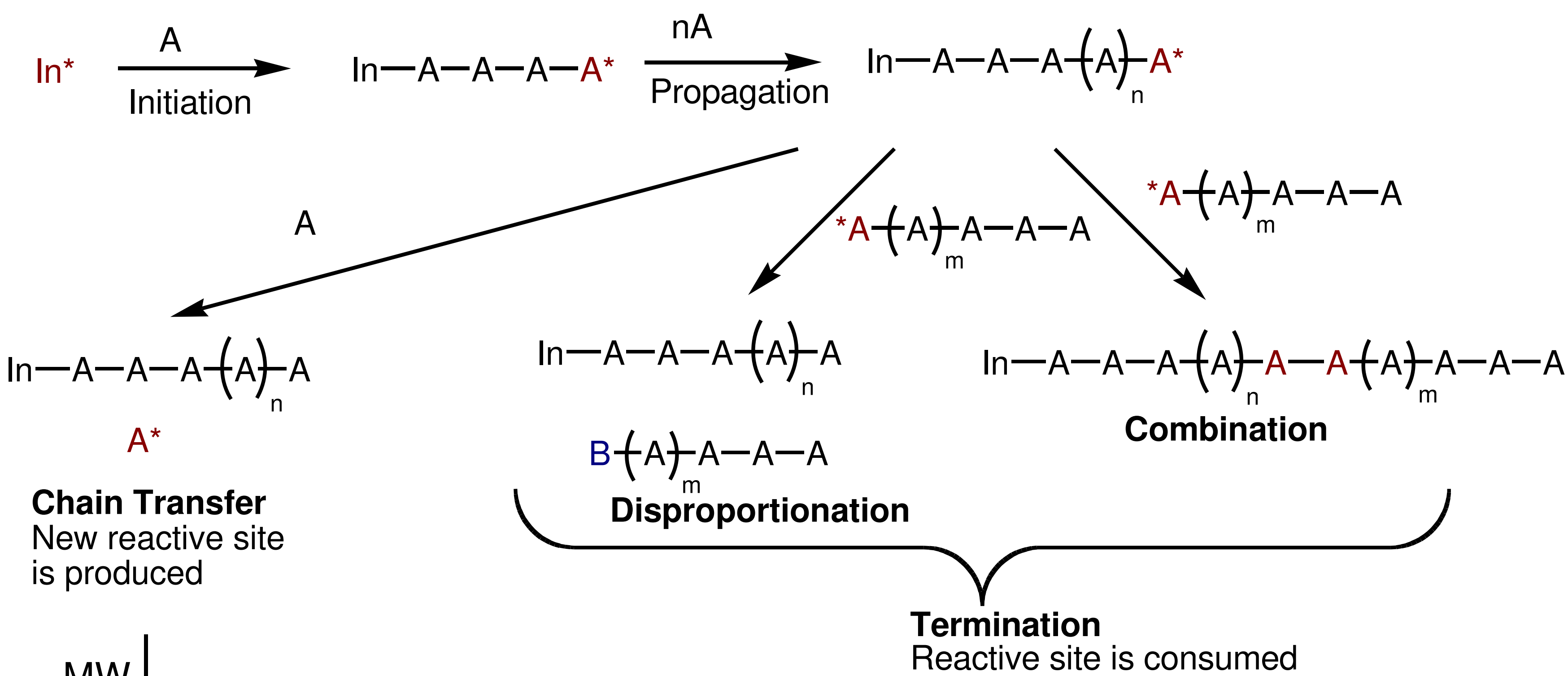
Propagation

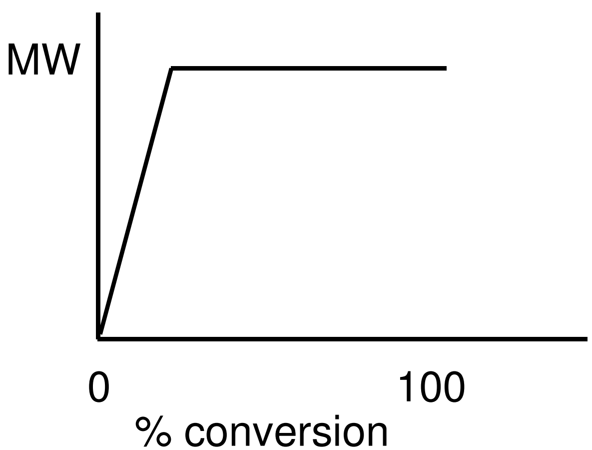
$$\mathrm{In}^* \xrightarrow[\text{Initiation}]{A} \mathrm{In{-}A{-}A}^* \quad \mathrm{A}$$

Addition Polymerization



Addition Polymerization

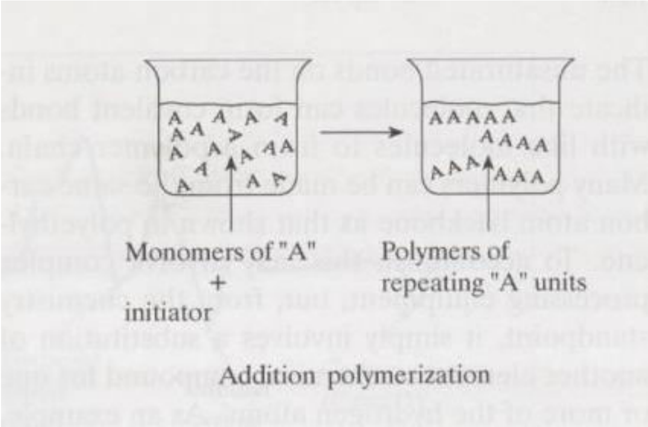




$$MW \propto \frac{k_{propagation}}{k_{termination}}$$

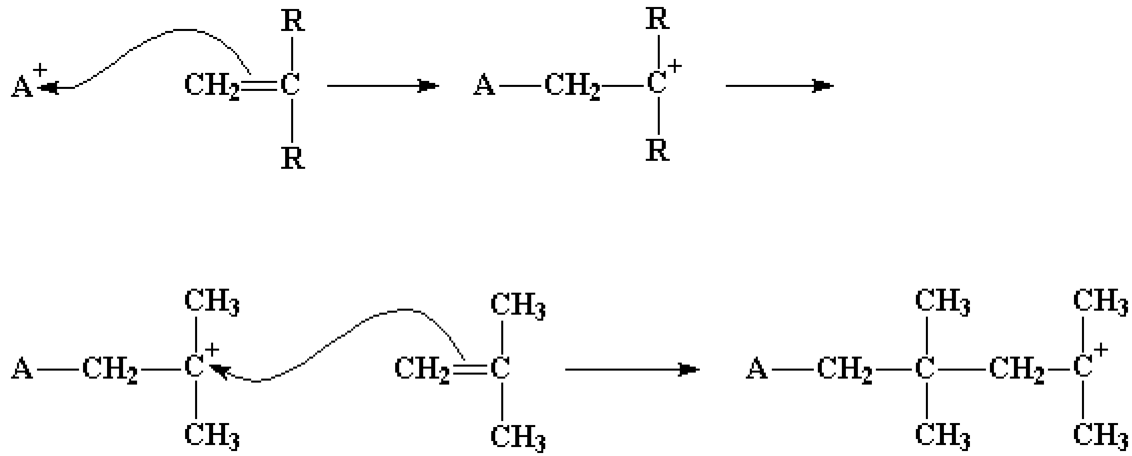
Addition Polymerization (Examples include: acrylic, polyethylene, polystyrene)

Addition polymerization comprised of 3 steps: initiation, propagation and termination.

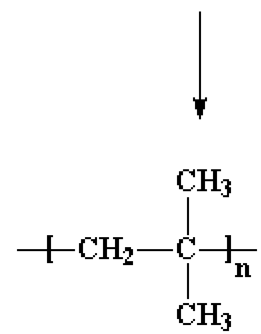


1. Initiation – double bonds in the ethylene "mers" break down under heat and pressure and begin to bond together – catalyst may be necessary.
2. Propagation – process 1 continues forming monomers together in chains.
3. Termination – all monomers used so reaction stops OR reaction can be quenched via water which cools the process down.

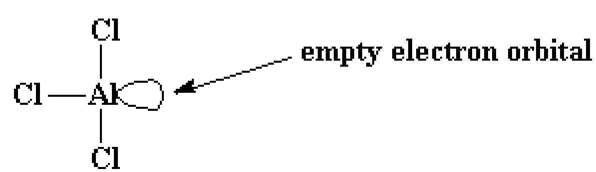
Simplest analogy: "mers" joining together similar to paper clips joined together to form a long chain.

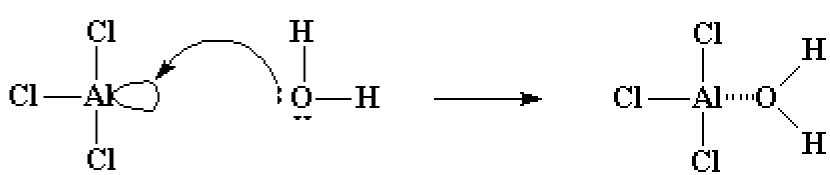


Note: When a line is drawn between two atoms, this represents a pair of electrons the atoms share. Sharing one pair of electrons makes a single bond. Sharing two pairs makes a double bond, shown by two lines. The curved arrows show the motion of a pair of electrons.

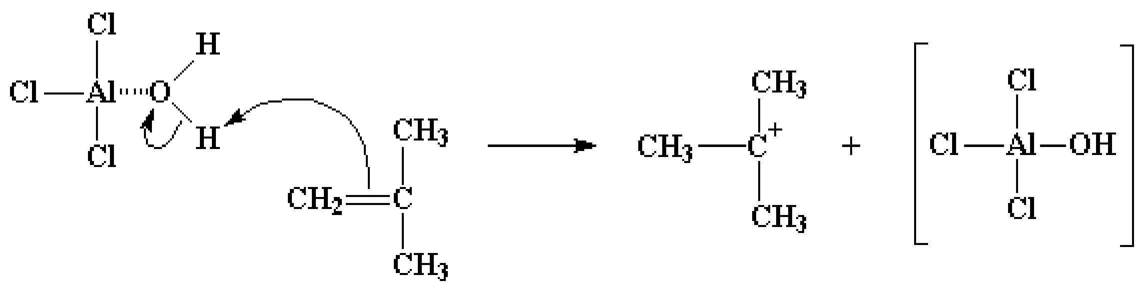


Many times, though, it starts off in little bit more complicated manner than that. Normally, the initiator used is something like aluminum trichloride, or $AlCl_3$. If you know the octet rule, you'll know that all atoms on the second row of the periodic table like to have eight electrons in their outermost shell, or level. The aluminum atom in AlCl3 is sharing electron pairs with only three other atoms, leaving it with only six electrons, two short of the magical octet. As it sits, it has a whole orbital (that is, a vacant slot where a pair of electrons should be) empty and ready for something to come along and fill it. It just so happens, much to the delight of that aluminum atom, that a very small amount of water is usually present in the system. Now the oxygen atom in water has two unshared pairs of electrons, and it most graciously donates a pair to the aluminum atom, forming an $AlCl_3$ and H_2O complex.

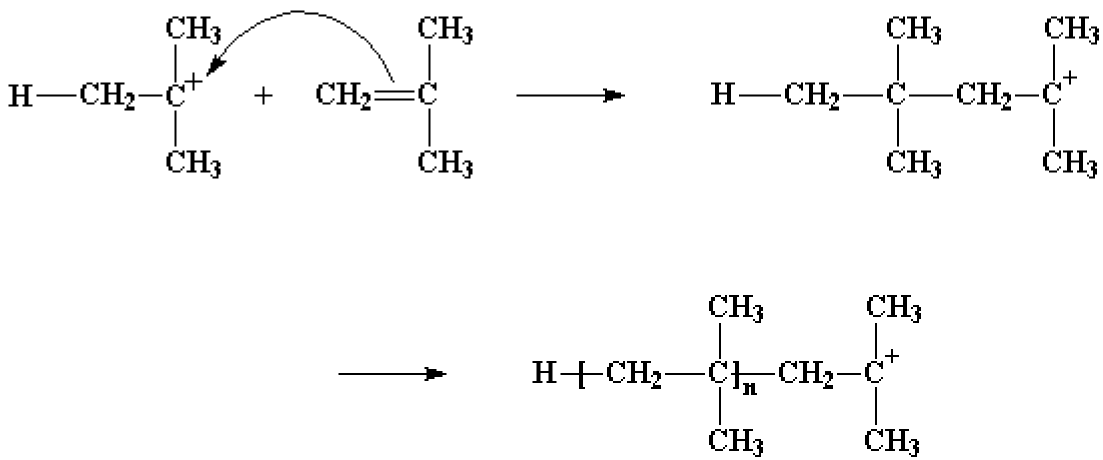




Oxygen, being very electronegative, will tend to pull the electrons it shares with the hydrogens atoms toward itself, leaving the hydrogen atoms with a slight positive charge. This leaves them ripe for attack by a pair of electrons from the double bond of a monomer molecule. The monomer in this way can swipe the hydrogen, making itself a cation, and the $AlCl_3/H_2O$ complex becomes its compliment anion, $AlCl_3OH^-$. This whole process by which the $AlCl_3/H_2O$ complex forms and reacts with the first monomer molecule is called *initiation*.

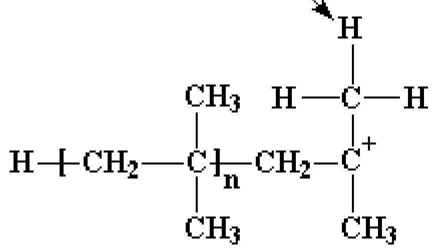


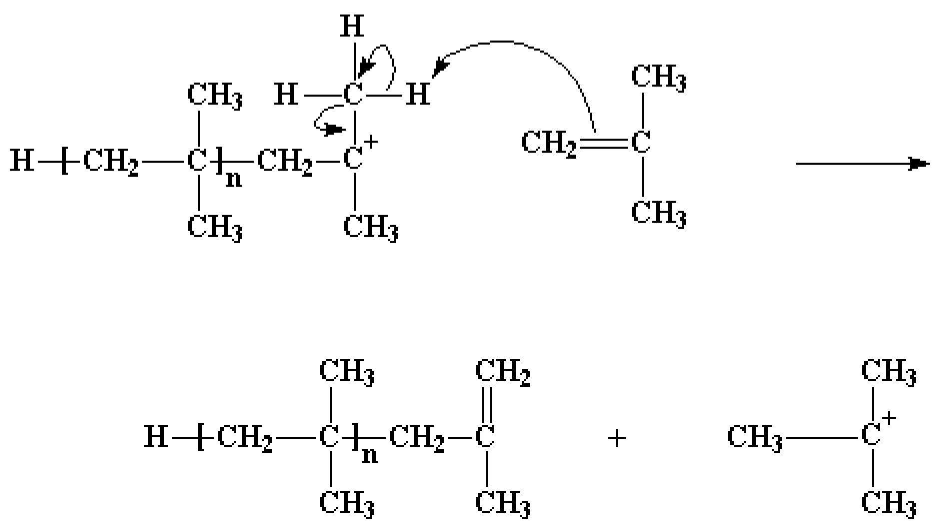
So the carbocation looks around, and finds a pair of electrons in the double bond of a nearby monomer molecule. (Remember there are two pairs of electrons in a double bond.) So the carbocation swipes those electrons, and in doing so forms a single bond with the monomer molecule. It also generates another carbocation, as you can see in the picture below. This can react with another monomer, and then another, and so on. Eventually we get a long polymer chain.



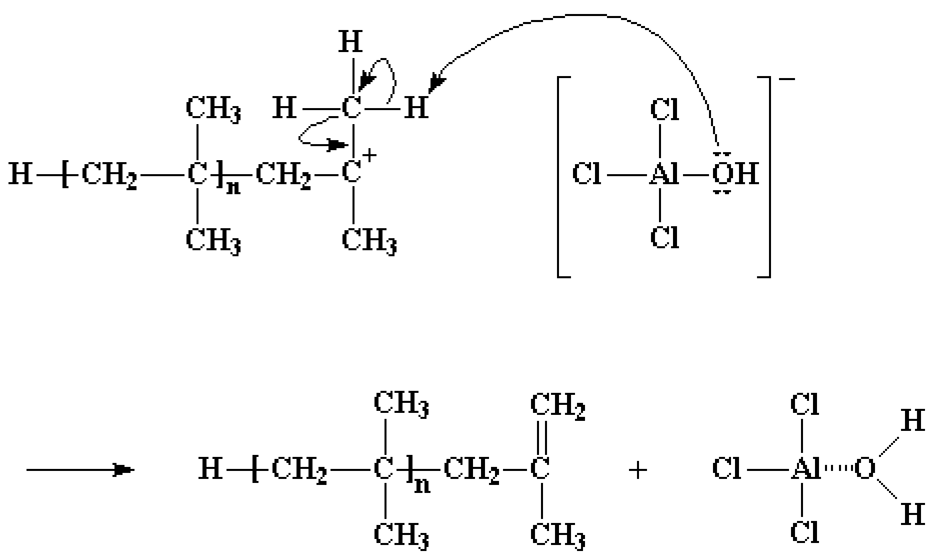
But how does it end? How does this cycle of adding more monomer molecules to the growing polymer stop? The most common way goes something like this... Imagine the growing chain of polyisobutylene. The methyl groups attached to the cationic carbon atom have a little problem: they've got hydrogen trouble. The hydrogens on these methyl groups will, without a whole lot of persuasion, break away and join other molecules. This is just what can happen when they come close to a molecule of monomeric isobutylene. Starved for electrons as they are, being part of a cation, these hydrogens are easily attacked by a pair of electrons from the carbon-carbon bond in the isobutylene molecule. When all the electrons are through rearranging themselves, as shown by the arrows, we're left with a neutral polymer chain with a double bond at its end, and a new cation, formed from the isobutylene molecule. The polymer chain end is now neutral, and can no longer react and grow. But the new cation can start a new chain growing, in the same way as our initiator molecule did. This process is called *chain transfer*. It also happens in free radical polymerization, and other kinds of polymerization as well.

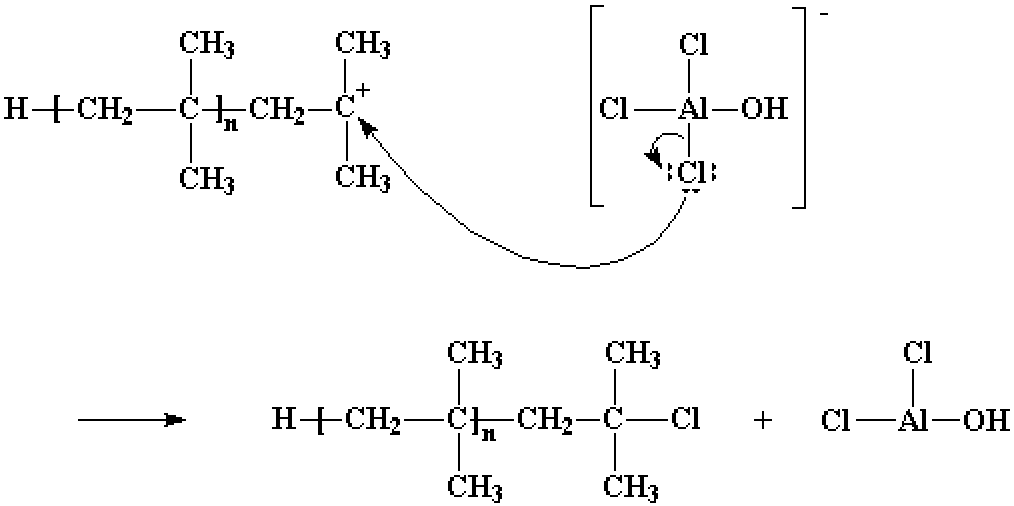
These hydrogen atoms like to split off and join other molecules





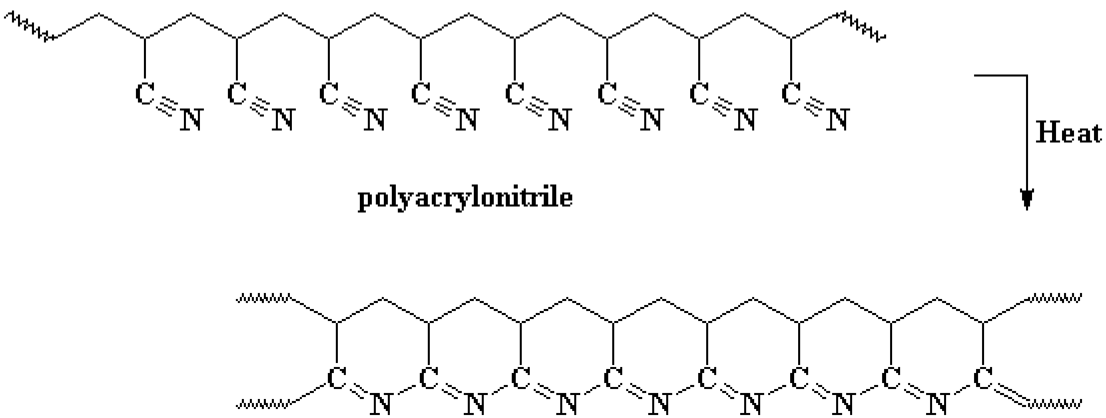
That particular kind of chain transfer is called *chain transfer to monomer*. But there's another kind of chain transfer. To understand, it helps to remember that for every cation, there is an anion lurking somewhere in the same beaker. Remember that $AlCl_3OH^-$ ion? As we all know, cations and anions have this nasty tendency to react with each another, which can be troublesome when we want our cation to react with something else, like a monomer molecule. Let's take a look at how this happens.





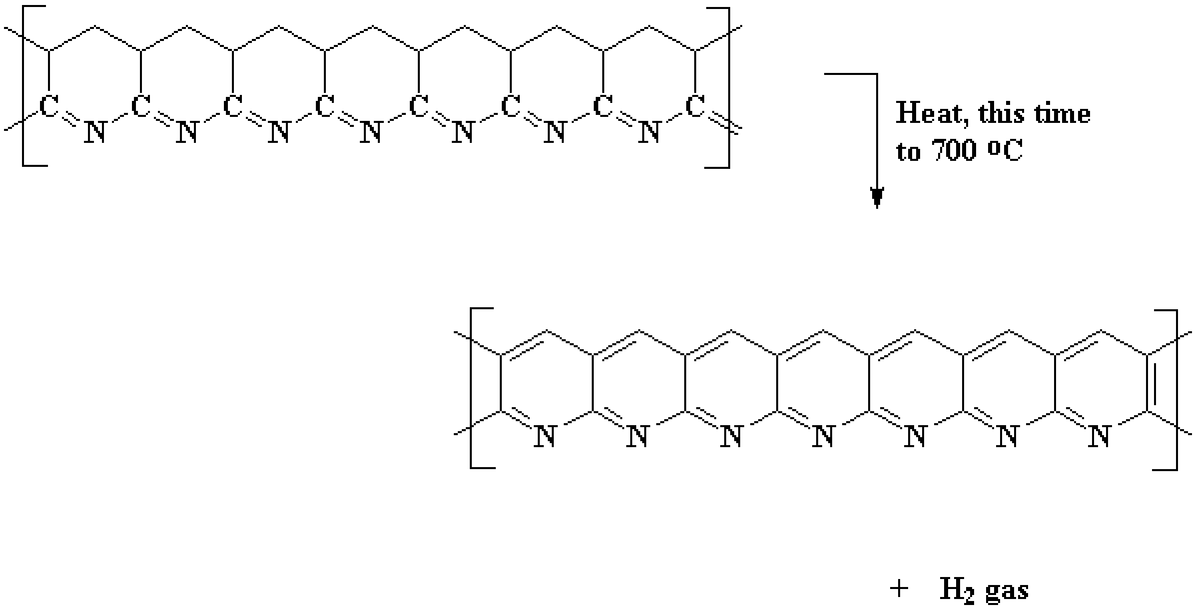
This process is called *termination*, because no new chains are started. It's the last of the three major steps in any chain growth polymerization, the first two being initiation and propagation, of course. When termination happens, the polymerization is over.

We start off with another polymer, one called polyacrylonitrile. We take this polymer, and heat it up. We're not sure just exactly what happens when we do this, but we do know that the end result is carbon fiber. We think the reaction happens something like this: when we heat the polyacrylonitrile, the heat causes the cyano repeat units to form cycles!



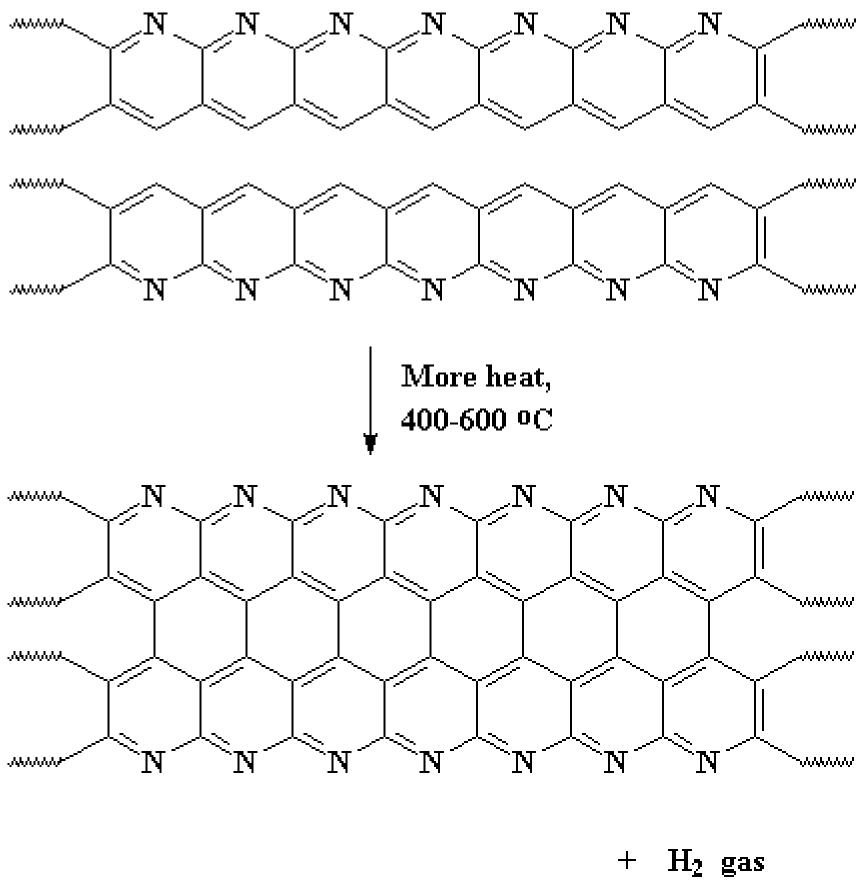
Then you know what we do? We heat it again! This time we turn the heat up higher, and our carbon atoms kick off their hydrogens, and the rings become aromatic. This polymer is a series of fused pyridine rings.

Making Carbon Fiber



Making Carbon Fiber

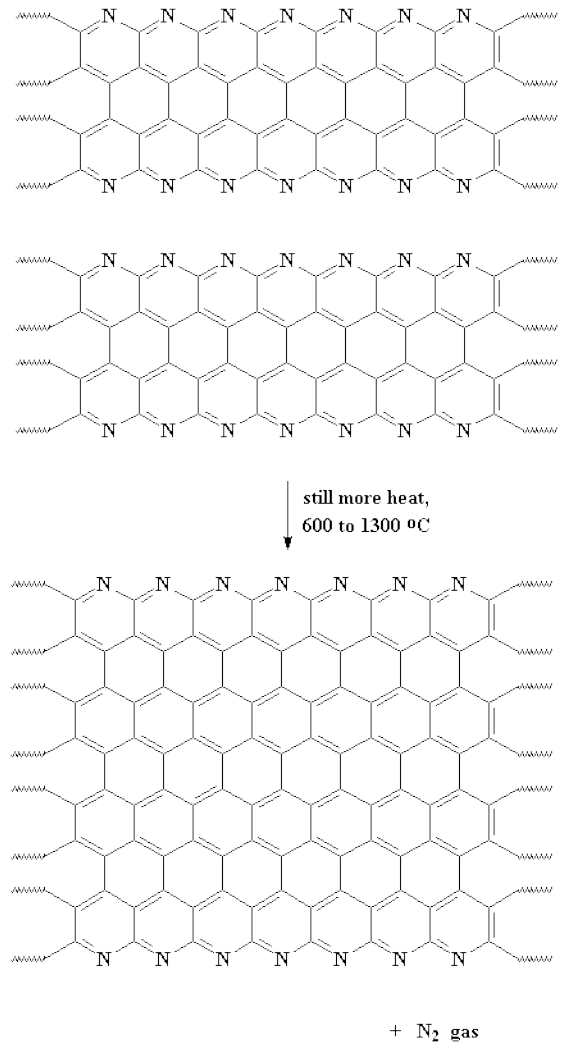
Then...guess what?...we heat it...AGAIN! Slow roasting the polymer some more at around 400-600 °C causes adjacent chains to join together like this:

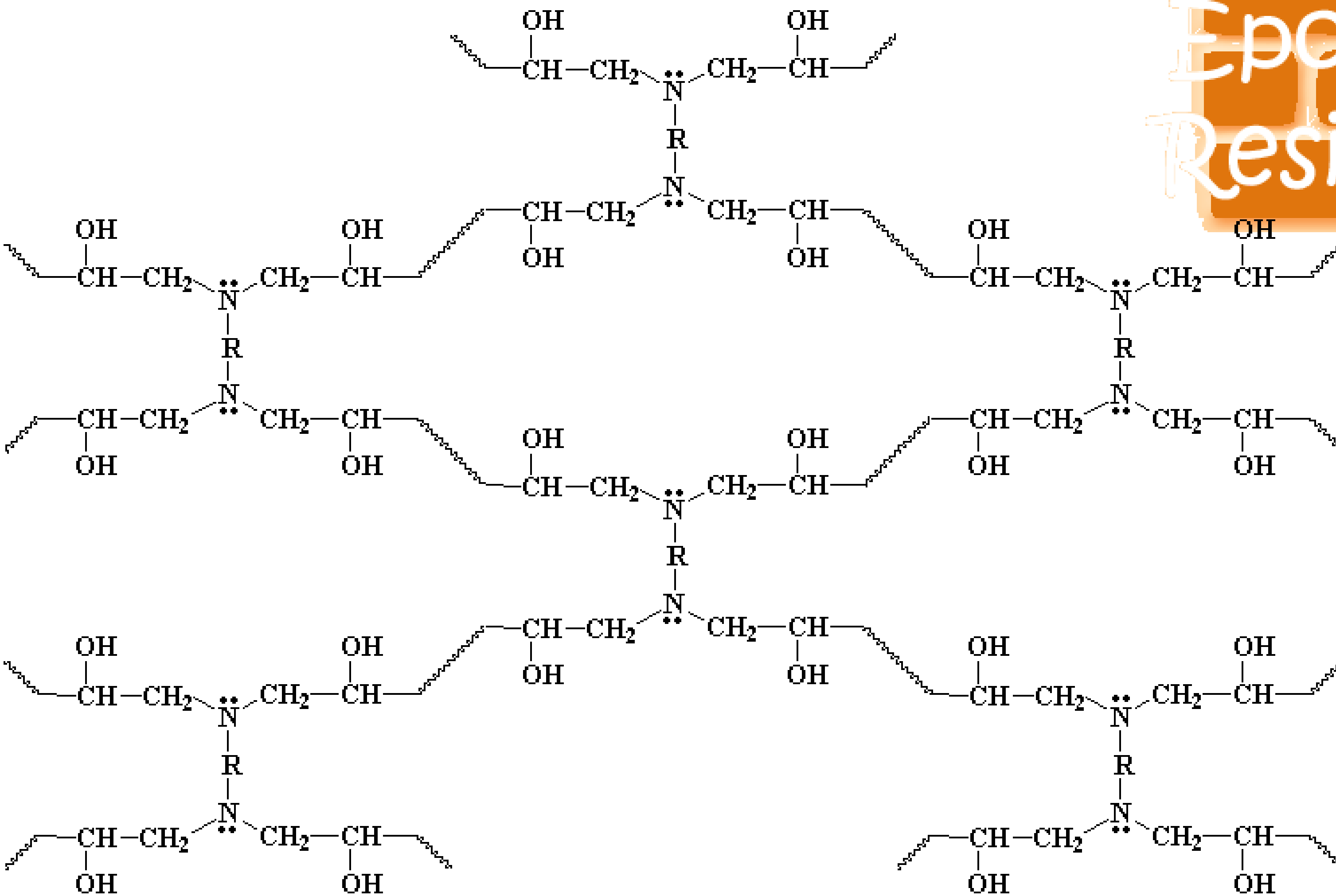


Making Carbon Fiber

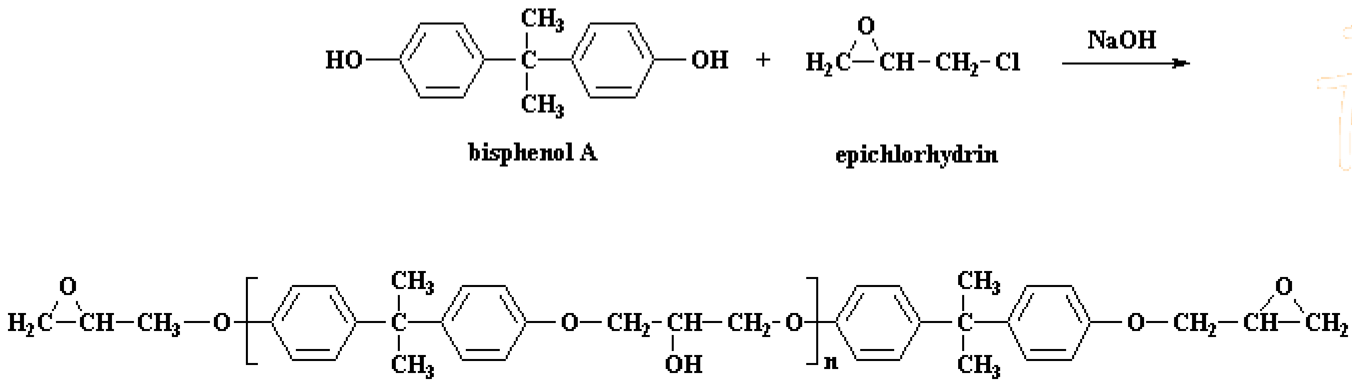
This expels hydrogen gas, and gives us a ribbon-like fused ring polymer. But don't think we're done yet! Next we crank up the heat, anywhere from 600 all the way up to 1300 °C. When this happens, our newly formed ribbons will themselves join together to form even wider ribbons like this:

When this happens, we expel nitrogen gas. As you can see on the polymer we get, it has nitrogen atoms along its edges, and these new wide ribbons can then merge to form even wider ribbons. As this happens, more and more nitrogen is expelled. When we're through, the ribbons are really wide, and most of the nitrogen is gone, leaving us with ribbons that are almost pure carbon in the graphite form. That's why we call these things *carbon* fibers.





Making Epoxy Resins



Epoxy resins make great adhesives, and are one of the few adhesives that can be used on metals. But they're also used for things like protective coatings, and as materials in things like electronic circuit boards and for patching holes in concrete pavement. What? You want more? Epoxies are also used to make composites. One way we make composites using epoxies is with a nifty process called SCRIMP.

Differences between step-growth polymerization and chain-growth polymerization

Step-growth polymerization	Chain-growth polymerization
Growth throughout matrix	Growth by addition of monomer only at one end of chain
Rapid loss of monomer early in the reaction	Some monomer remains even at long reaction times
Same mechanism throughout	Different mechanisms operate at different stages of reaction (i.e. Initiation, propagation and termination)
Average molecular weight increases slowly at low conversion and high extents of reaction are required to obtain high chain length	Molar mass of backbone chain increases rapidly at early stage and remains approximately the same throughout the polymerization
Ends remain active (no termination)	Chains not active after termination
No initiator necessary	Initiator required