POLYMER

SCIENCE

11

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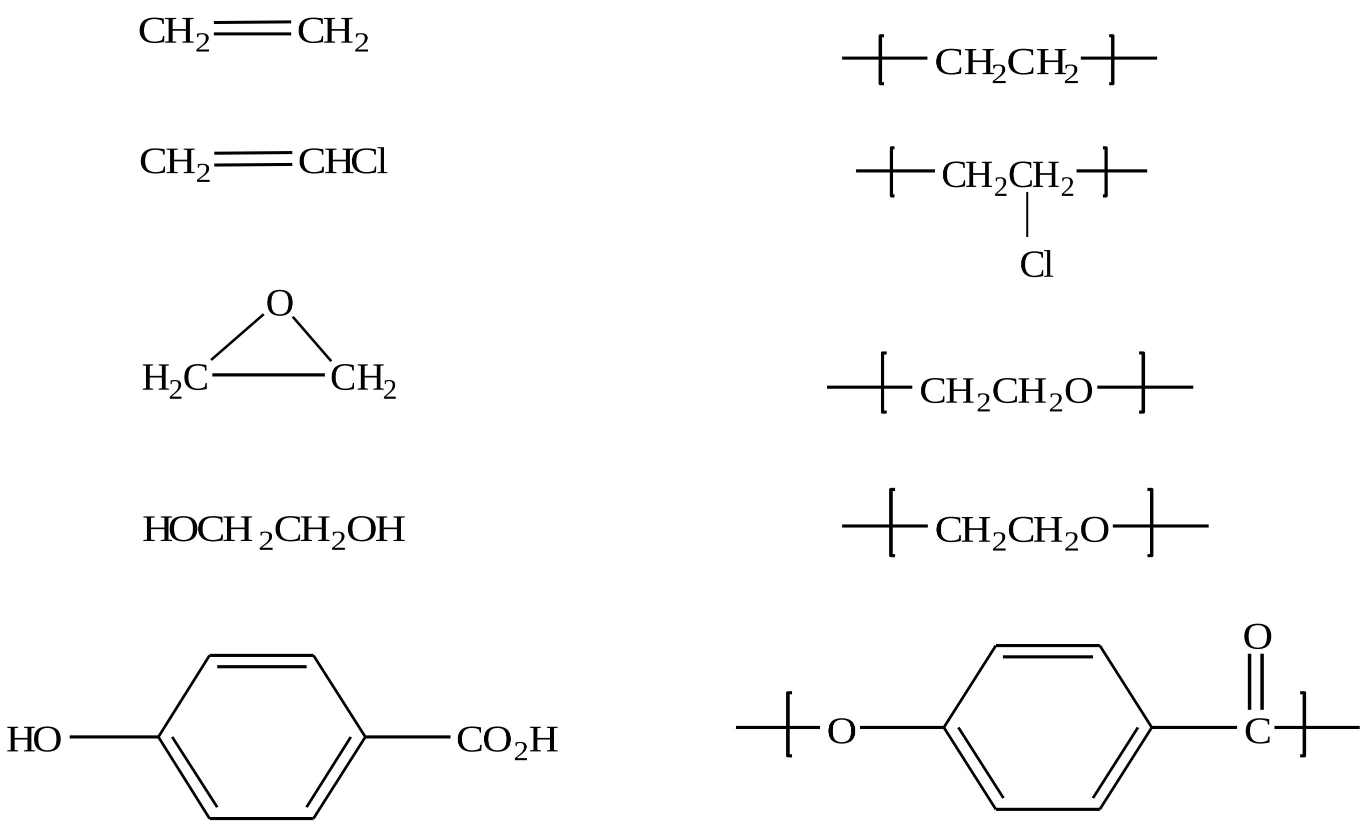
Chapter 1. Basic principles

E. Examples of monomers and polymers

Monomer | **Polymer**



1.2 Definitions

A. Acoording to the amount of repeating units

- **monomer** : one unit
- **oligomer** : few
- **polymer** : many (poly – many, mer – part)
- **telechelic polymer** : polymer containing reactive end group

  (tele = far, chele = claw)
- **telechelic oligomer** : oligomer containing reactive end group
- **macromer(=macro monomer)** : monomer containing long chain

1.2 Definitions

B. DP : Degree of polymerization

The total number of repeating units contained terminal group

C. The kinds of applied monomers

- One kind : Homopolymer
- Two kinds : Copolymer
- Three kinds : Terpolymer

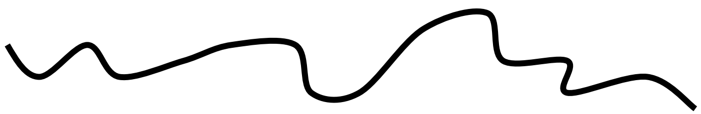
D. Types of copolymer

- Homopolymer : -A-A-A-A-A-A-A-A-
- Random copolymer : -A-B-B-A-B-A-A-B-
- Alternating copolymer : -A-B-A-B-A-B-A-B-
- Block copolymer : -A-A-A-A-B-B-B-B-
- Graft copolymer : -A-A-A-A-A-A-A-A-

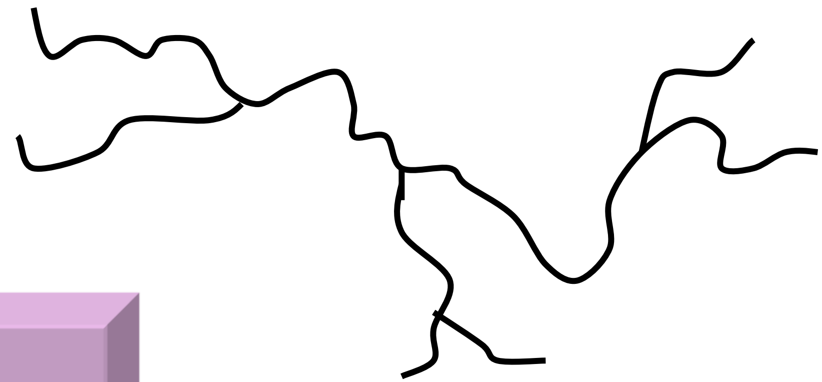
```
                    -A-A-A-A-A-A-A-A-
                          |
                          B-B-B-B-B-
```

E. Representation of polymer types

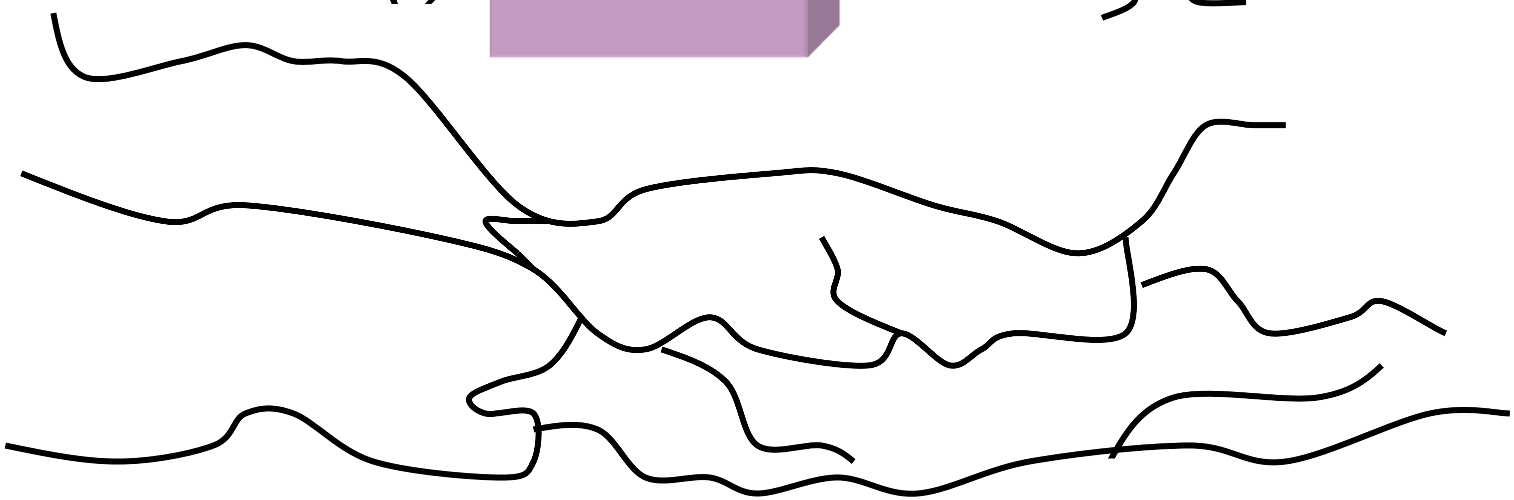
(a) linear



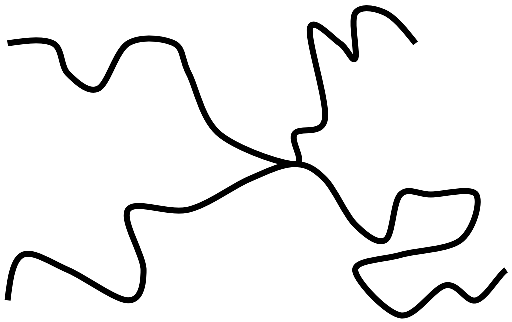
(b) branch



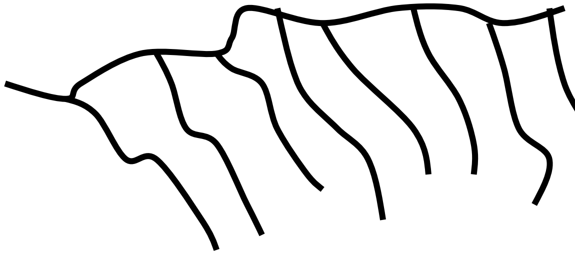
(c) network



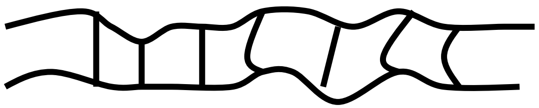
F. Representation of polymer architectures



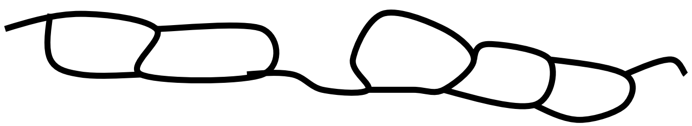
(a) star polymer



(b) comb polymer

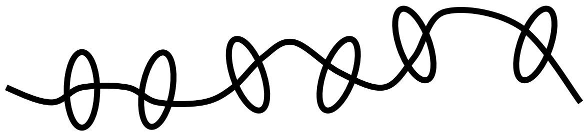


(c)ladder polymer



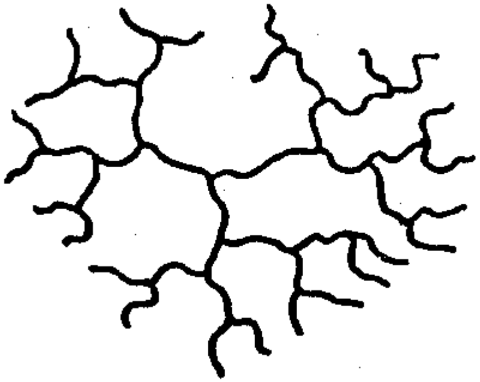
(d) semi- ladder
(or stepladder) polymer

F. Representation of polymer architectures



(e) polyrotaxane

(f) polycatenane



(g) dendrimer

G. Thermoplastic and thermoset (reaction to temperature)

- Thermoplastic : Linear or branched polymer
- Thermoset : Network polymer

1.3 Polymerization Processes

A. Classification of polymers to be suggested by Carothers

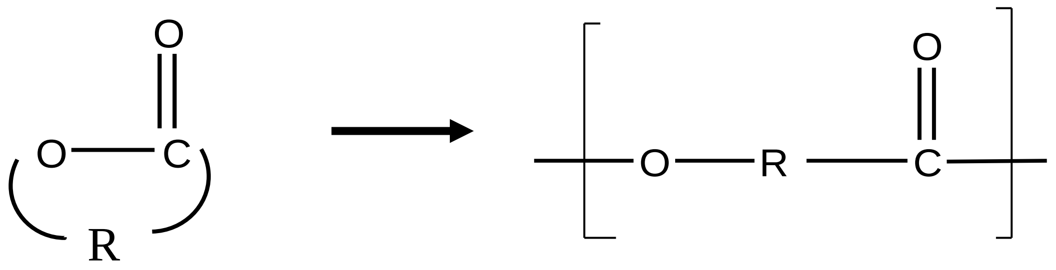
- **Addition polymers : repeating units and monomers are same**

- **Condensation polymers : repeating units and monomers are not equal, to be split out small molecule**

Other examples

1. **Polyester from lactone (1.7) &**

   from ω-hydroxycarboxylic acid (1.8)



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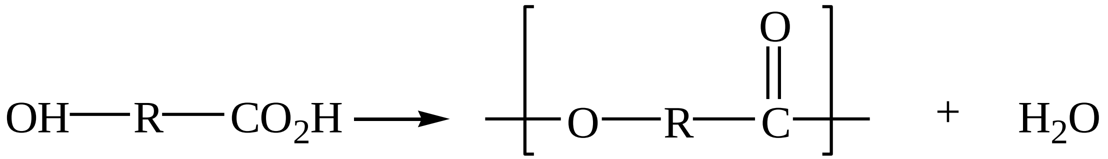
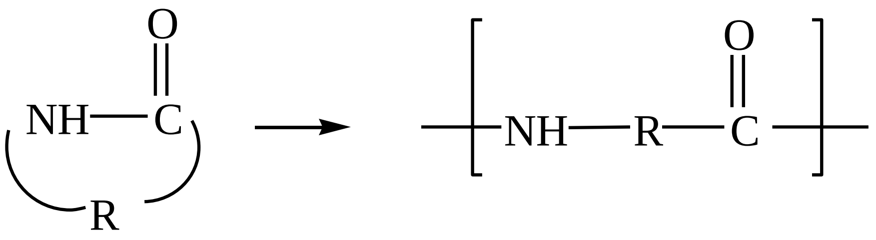


(1.8)

2. Polyamide from lactam (1.9), and
from ω-aminocarboxylic acid (1.10)



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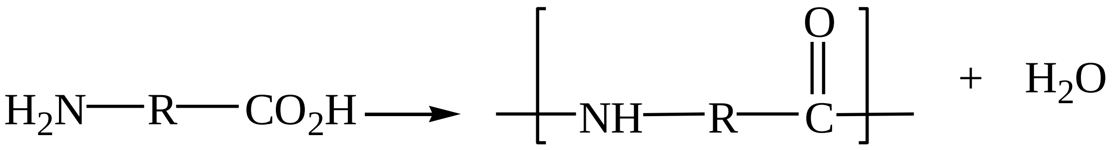
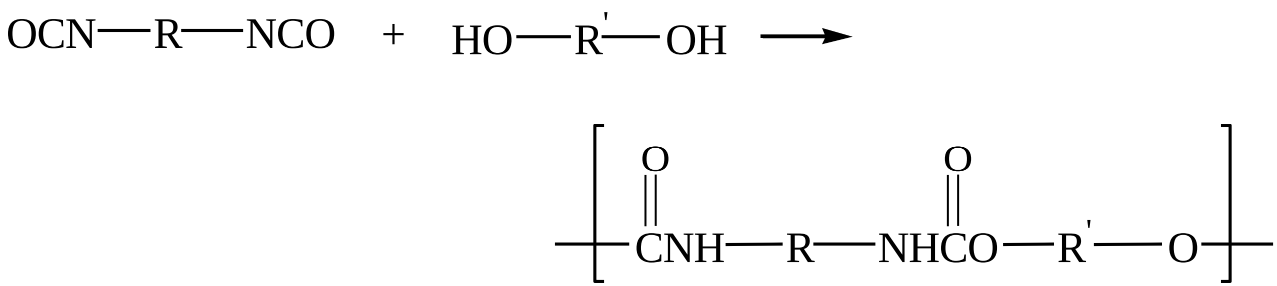


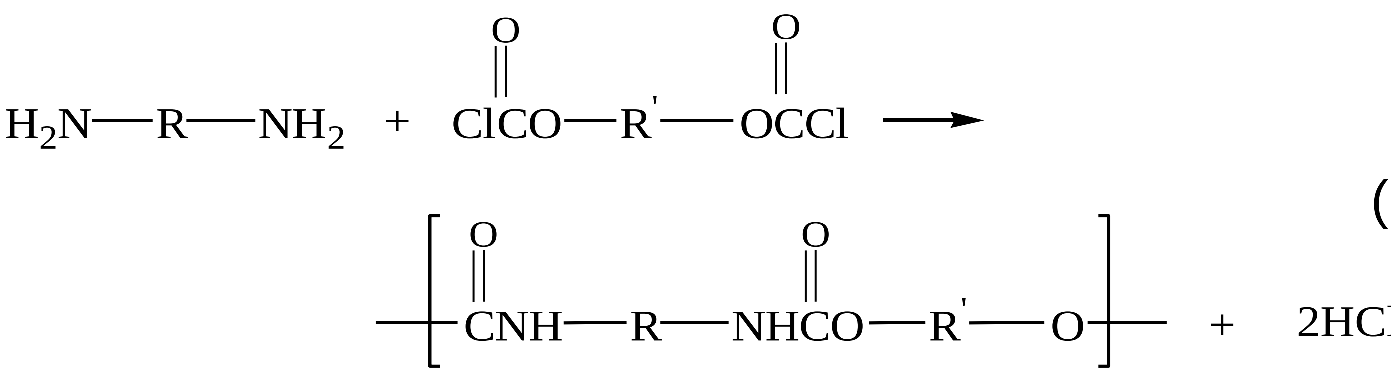
(1.10)

Other examples

3. Polyurethane from diisocyanate and dialcohol(1.11) and from diamine and bischloroformate(1.12):



(1.11)



(1.12)

Other examples

4. Hydrocarbon polymer from ethylene (1.13), and from α,ω-dibromide (1.14)

$$CH_2{=}CH_2 \xrightarrow{\text{initiator}} \left[CH_2CH_2 \right] \qquad (1.13)$$

$$BrCH_2(CH_2)_8CH_2Br \xrightarrow{2Na} \left[CH_2CH_2 \right]_5 + 2NaBr \qquad (1.14)$$

1.3 Polymerization Processes

B. Modern classification of polymerization according to polymerization mechanism

Step growth polymerization : Polymers build up stepwise

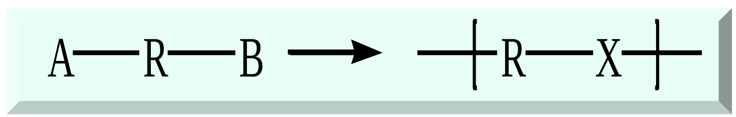
Chain growth polymerization : Addition polymerization
molecular weights increase successively,
one by one monomer

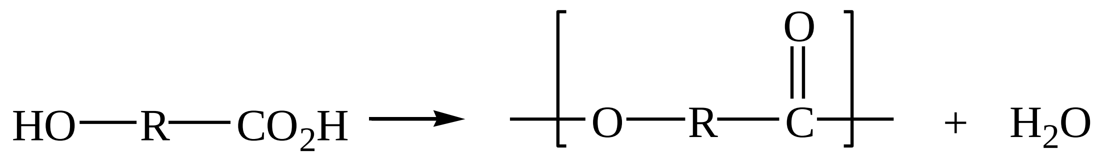
Ring-opening polymerization may be either step
or chain reaction

1.4 Step-reaction Polymerization

A. Monomer to have difunctional group

1. One having both reactive functional groups in one molecule





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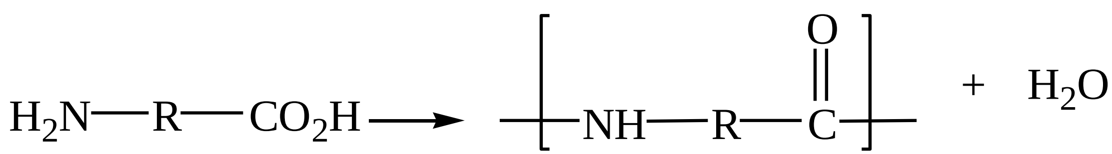
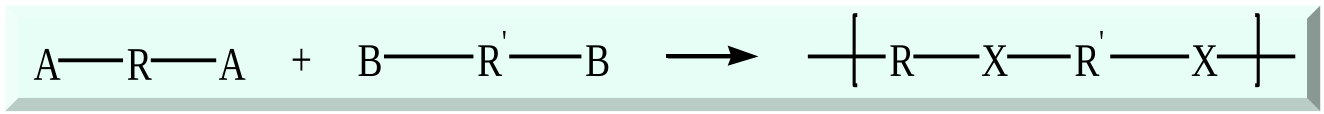
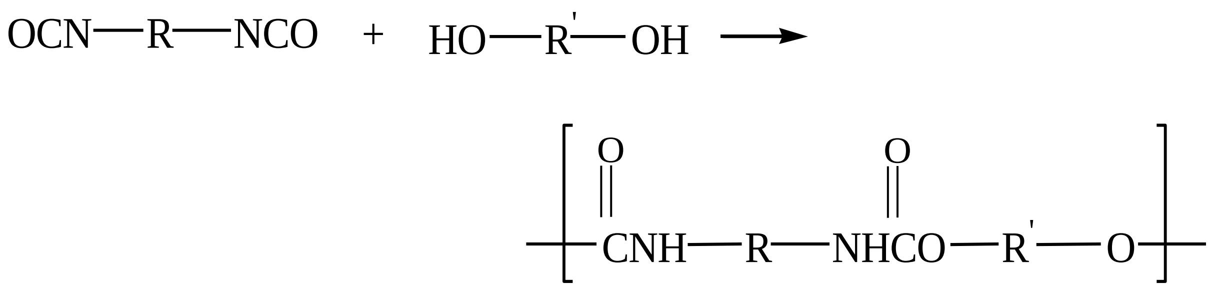


(1.10)

2. Other having two difunctional monomers





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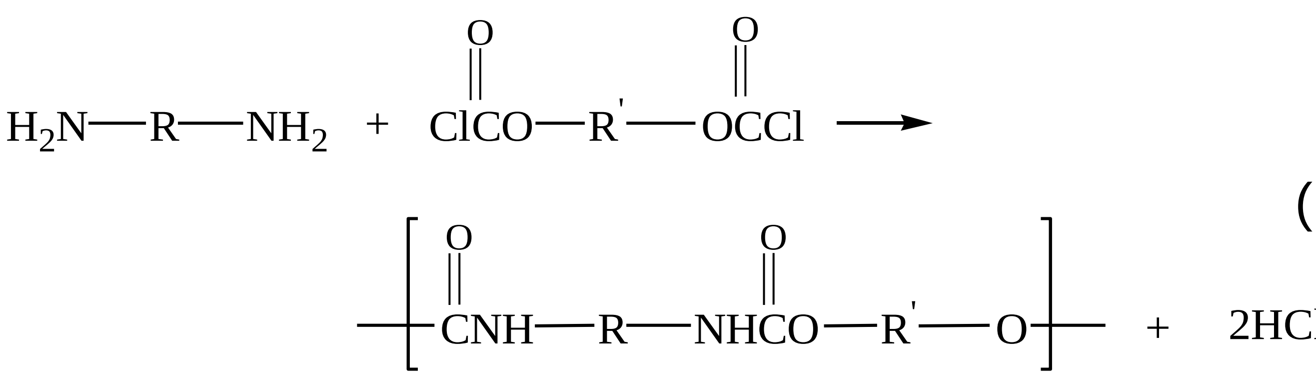
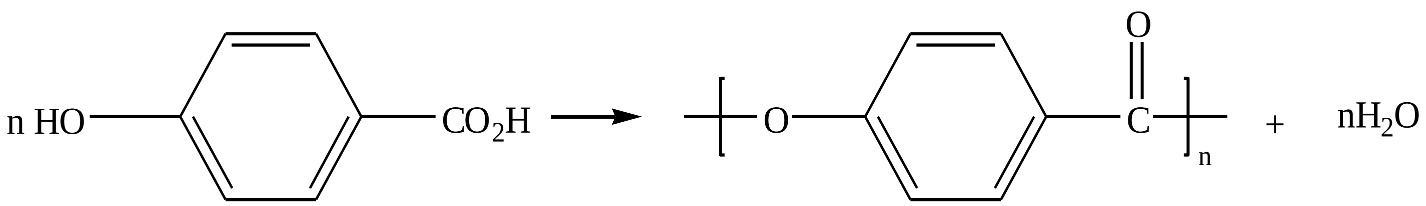


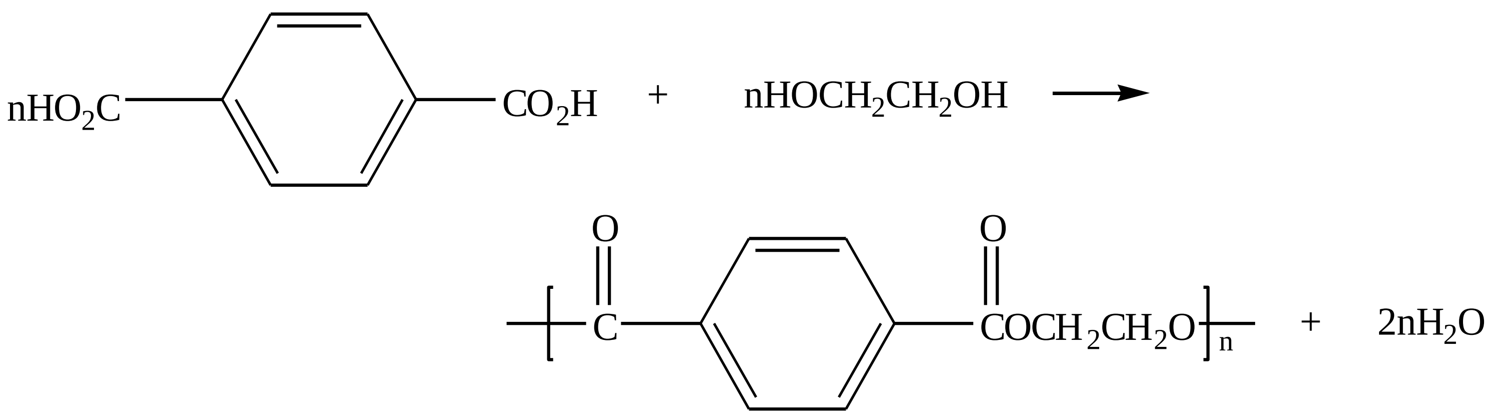
(1.12)

B. Reaction : Condensation reaction using functional group

Example - Polyesterification



(1.3)



(1.4)

C. Carothers equation

(N_O : number of molecules
N : total molecules after a given reaction period.
$N_O - N$: The amount reacted
P : The reaction conversion)

$$P = \frac{N_O - N}{N_O} \qquad \text{Or} \qquad N = N_O(1 - P)$$

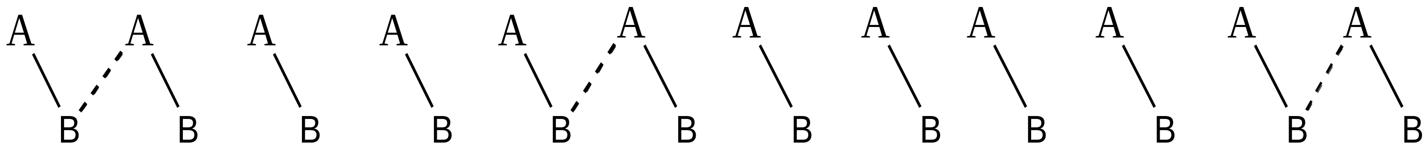
($\overline{DP}$ is the average number of repeating units of all molecules present)

$$\overline{DP} = N_O/N$$

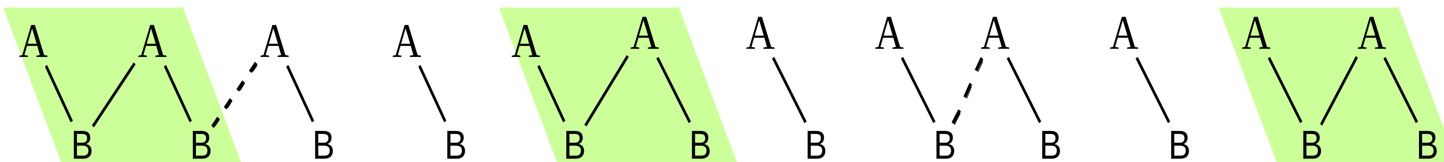
$$\overline{DP} = \frac{1}{1 - P}$$

For example
At 98% conversion → $\overline{DP} = \frac{1}{1 - 0.98}$

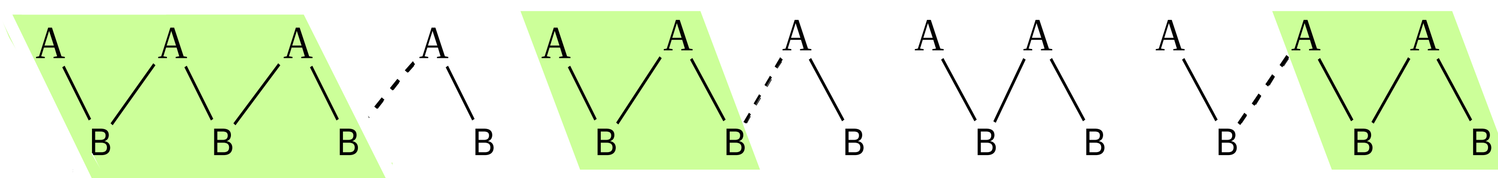
(A) Unreacted monomer



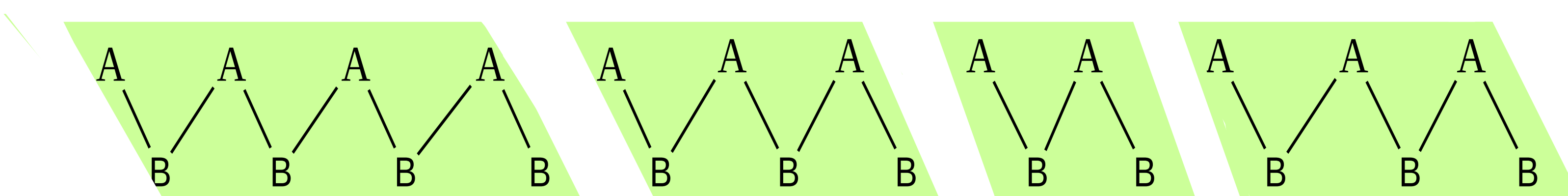
(B) 50% reacted, $\overline{DP}$ = 1.3



(C) 75% reacted, $\overline{DP}$ = 1.7



(D) 100% reacted, $\overline{DP}$ = 3



1.5 Chain-reaction Polymerization

A. Monomer : vinyl monomer

$_{\chi}CH_2=CH_2$

B. Reaction : Addition reaction initiated by active species

C. Mechanism :

- **Initiation**

  $R\cdot + CH_2=CH_2 \rightarrow RCH_2CH_2\cdot$

- **Propagation**

  $RCH_2CH_2\cdot + CH_2=CH_2 \rightarrow RCH_2CH_2CH_2CH_2\cdot$

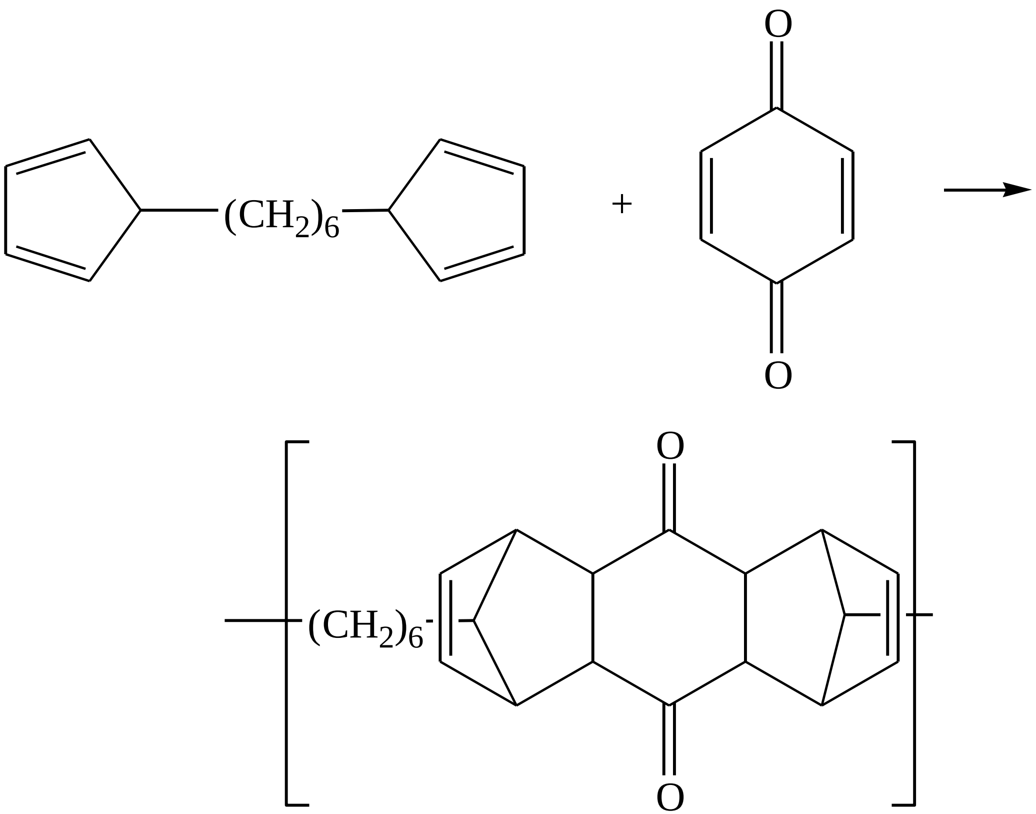
TABLE 1.1 Comparison of Step-Reaction and Chain-Reaction Polymerization

Step Reaction	***Chain Reaction***
Growth occurs throughout matrix by reaction between monomers, oligomers, and polymers	Growth occurs by successive addition of monomer units to limited number of growing chains
$\overline{DP}$[a] low to moderate	$\overline{DP}$ can be very high
Monomer consumed rapidly while molecular weight increases slowly	Monomer consumed relatively slowly, but molecular weight increases rapidly
No initiator needed; same reaction mechanism throughout	Initiation and propagation mechanisms differe
No termination step; end groups still reactive	Usually chain-terminating step involved
Polymerization rate decreases steadily as functional groups consumed	Polymerizaion rate increases initially as initiator units generated; remains relativel constant until monomer depleted

[a] $\overline{DP}$, *average degree of polymerization*.

1.6 Step-reaction Addition and Chain-reaction Condensation

A. Step-reaction Addition.



(1.15)

1.6 Step-reaction Addition and Chain-reaction Condensation

B. Chain-reaction Condensation

$$CH_2N_2 \xrightarrow{BF_3} \left[CH_2 \right]_{} + N_2 \qquad (1.16)$$

1.7 Nomenclature

A. Types of Nomenclature

a. Source name : to be based on names of corresponding monomer

Polyethylene, Poly(vinyl chloride), Poly(ethylene oxide)

b. IUPAC name : to be based on CRU, systematic name

Poly(methylene), Poly(1-chloroethylene), Poly(oxyethylene)

c. Functional group name :

Acoording to name of functional group in the polymer backbone

Polyamide, Polyester

1.7 Nomenclature

d. **Trade name** : The commercial names by manufacturer Teflon, Nylon

e. **Abbreviation name** : PVC, PET

f. **Complex and Network polymer** : Phenol-formaldehyde polymer

g. **Vinyl polymer** : Polyolefin

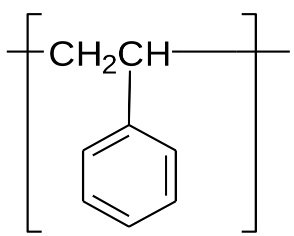
1.7.1 Vinyl polymers

A. Vinyl polymers

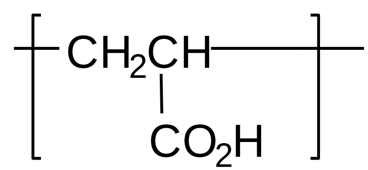
a. **Source name** : Polystyrene, Poly(acrylic acid),
Poly(α-methyl styrene), Poly(1-pentene)

b. **IUPAC name** : Poly(1-phenylethylene), Poly(1-carboxylatoethylene)
Poly(1-methyl-1-phenylethylene), Poly(1-propylethylene)

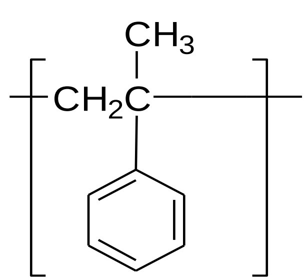
Polystyrene



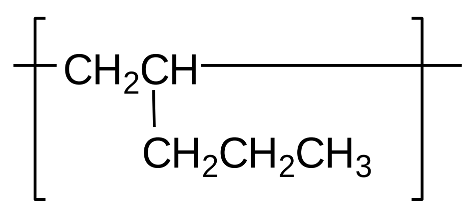
Poly(acrylic acid)



Poly(α-methylstyrene)

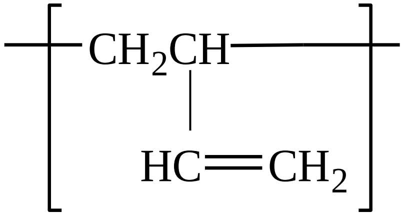


Poly(1-pentene)

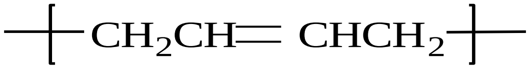


1.7.1 Vinyl polymers

B. Diene monomers



1,2-addition



1,4-addition

Source name : 1,2-Poly(1,3-butadiene)   1,4-Poly(1,3-butadiene)

IUPAC name : Poly(1-vinylethylene)   Poly(1-butene-1,4-diyl)

cf) Table 1.2

1.7.2 Vinyl copolymer

Systematic

Poly[styrene-co-(methyl methacrylate)]

Poly[styrene-*alt*-(methyl methacrylate)]

Polystyrene-*block*-poly(methyl methacrylate)

Polystyrene-*graft*-poly(methyl methacrylate)

Concise

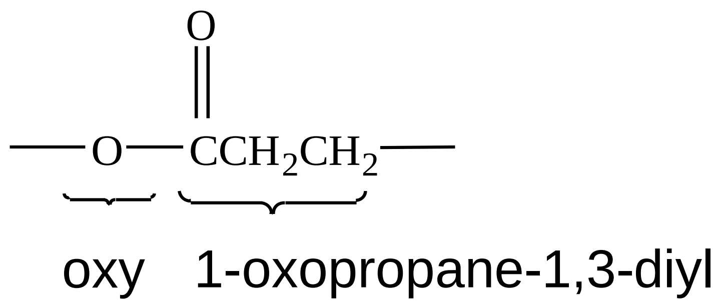
Copoly(styrene/methyl methacrylate)

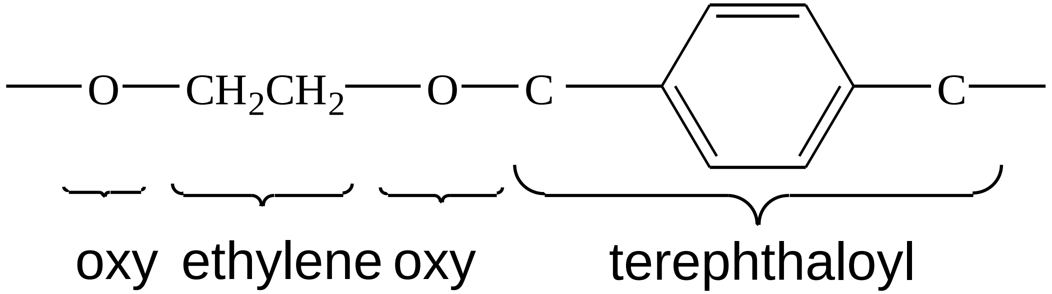
Alt-copoly(styrene/methyl methacrylate)

Block-copoly(styrene/methyl methacrylate)

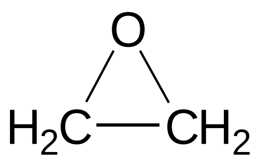
Graft-copoly(styrene/methyl methacrylate)

1.7.3 Nonvinyl Polymers





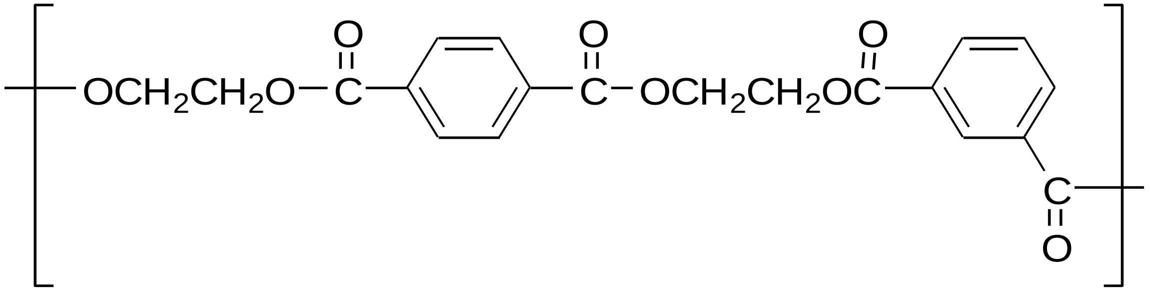
* Representative Nomenclature of Nonvinyl Polymers

Monomer structure	Polymer repeating unit	Source or Common Name	IUPAC name
	$\left[\!-CH_2CH_2O-\!\right]$	Poly(ethylene oxide)	Poly(oxyethylene)
$HOCH_2CH_2OH$	$\left[\!-CH_2CH_2O-\!\right]$	Poly(ethylene glycol)	Poly(oxyethylene)
$H_2N(CH_2)_6NH_2$ $HO_2C(CH_2)_8CO_2H$	$\left[\!-NH(CH_2)_6NHC(=O)(CH_2)_8C(=O)-\!\right]$	Poly(hexamethylene sebacamide) or Nylon6,10	Poly(iminohexane-1,6-diyliminosebacoyl)

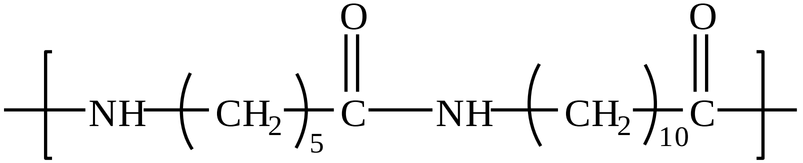
cf) Table 1.3

1.7.4 Nonvinyl copolymers

a. Poly(ethylene terephthalate-*co*-ethylene isophthalate)



b. Poly[(6-aminohexanoic acid)-*co*-(11-aminoundecanoic acid)]



1.7.5 End Group

$$H\!-\!\left[\!-\!OCH_2CH_2\!-\!\right]\!-\!OH$$

α-Hydro-ω-hydroxypoly(oxyethylene)

1.7.6 Abbreviations

PVC	Poly(vinyl chloride)
HDPE	High-density polyethylene
LDPE	Low-density polyethylene
PET	Poly(ethylene terephthalate)

TABLE 1.4 Commodity Plastic

Type	*Abbreviation*	*Major Uses*
Low-density polyethylene	LDPE	Packaging film, wire and cable insulation, toys, flexible bottles housewares, coatings
High-density Polyethylene	HDPE	Bottles, drums, pipe, conduit, sheet, film, wire and cable insulation
Polypropylene	PP	Automobile and appliance parts, furniture, cordage, webbing, carpeting, film packag
Poly(vinyl chloride)	PVC	Construction, rigid pipe, flooring, wire and cable insulation, film and sheet
Polystyrene	PS	Packaging (foam and film), foam insulation appliances, housewares, toys

1.8.2 Fibers

1) Cellulosic :

Acetate rayon, Viscose rayon

2) Noncellulosic :

Polyester, Nylon(Nylon6,6, Nylon6, etc)
Olefin
(PP, Copolymer(PVC 85%+PAN and others 15%; *vinyon*))

3) Acrylic :

Contain at least 80% acrylonitrile
(PAN 80% + PVC and others 20%)

1.8.3 Rubber (Elastomers)

1) Natural rubber :

cis-polyisoprene

2) Synthetic rubber :

Styrene-butadiene, Polybutadiene,
Ethylene-propylene(EPDM), Polychloroprene, Polyisoprene,
Nitrile, Butyl, Silicone, Urethane

3) Thermoplastic elastomer :

Styrene-butadiene block copolymer
(SB or SBS)

TABLE 1.7 Principal Synthetic Fibers

Type	***Description***
Cellulosic	
Acetate rayon	Cellulose acetate
Viscose rayon	Regenerated cellulose
Noncellulosic	
Polyester	Principally poly(ethylene terephthalate)
Nylon	Includes nylon 66, nylon 6, and a variety of other aliphatic and aromatic polyamides
Olefin	Includes polypropylene and copolymers of vinyl chloride, with lesser amounts of acrylonitrile, vinyl acetate, or vinylidene chloride (copolymers consisting of more than 85% vinyl chloride are called *vinyon* fibers)
Acrylic	Contain at least 80% acrylonitrile; included are *modacrylic* fibers comprising acrylonitrile and about 20% vinyl chloride or

1.9 Polymer Recycling

a. Durability of polymer property

1) Advantage : Good materials for use

2) Disadvantage : Environmental problem

b. Treatment of waste polymer : Incinerate,
Landfill, Recycling

ex) Waste Tire : Paving materials
Waste PET : To make monomer (hydrolysis)
To make polyol (glycolysis)

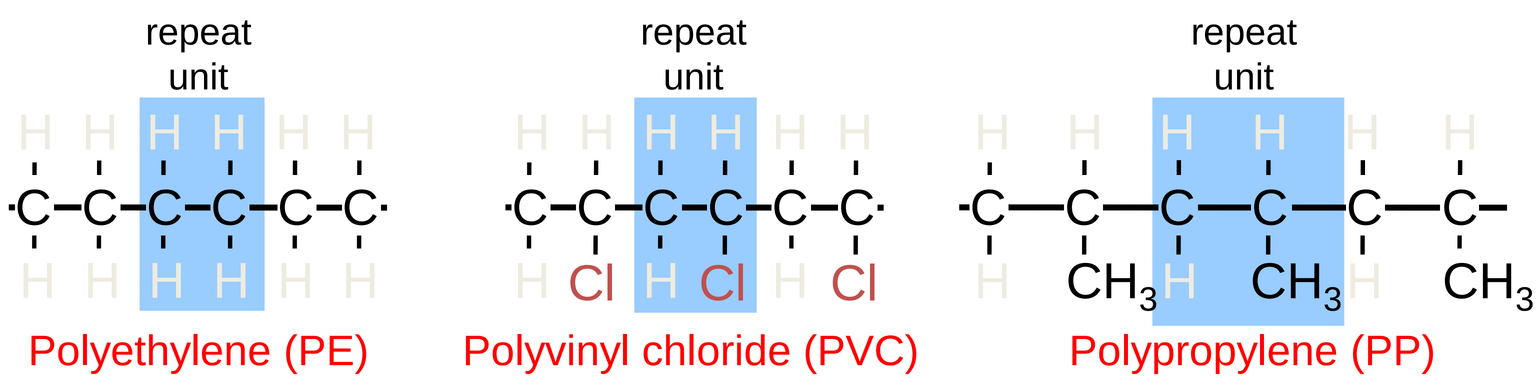
Polymers

What is a polymer?

Very Large molecules structures chain-like in nature.

Poly **mer**

many **repeat unit**

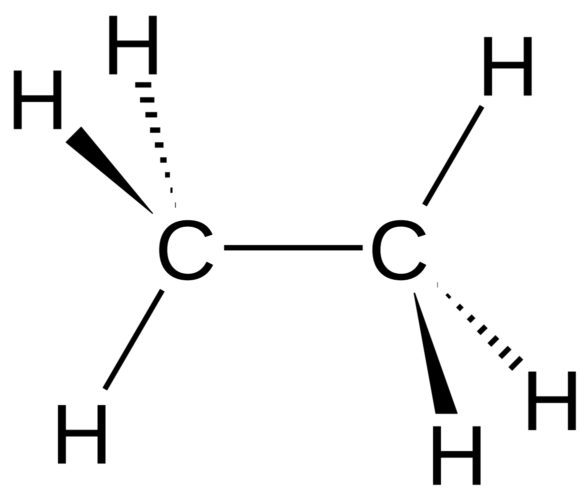


Adapted from Fig. 14.2, *Callister 7e.*

Polymer Composition

Most polymers are hydrocarbons
- **– i.e. made up of H and C**

- **Saturated hydrocarbons**
  - **Each carbon bonded to four other atoms**



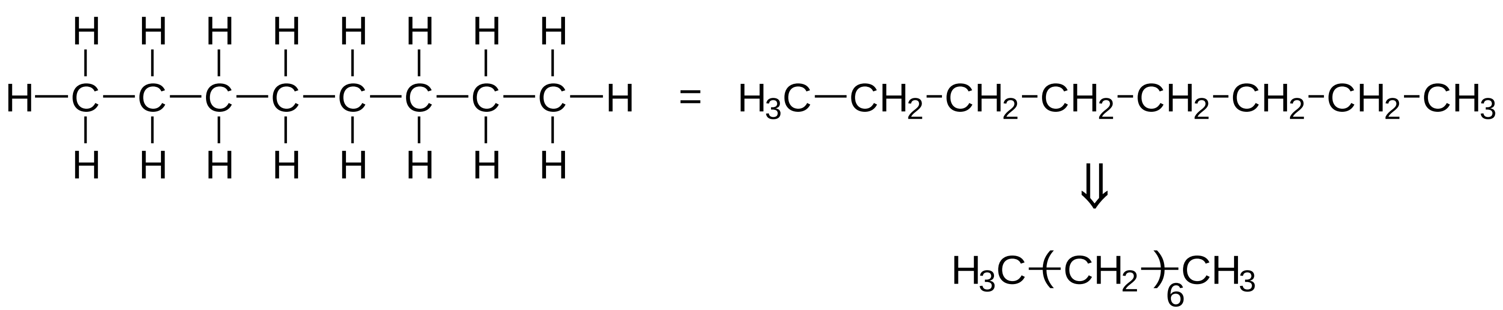
$$C_nH_{2n+2}$$

Isomerism

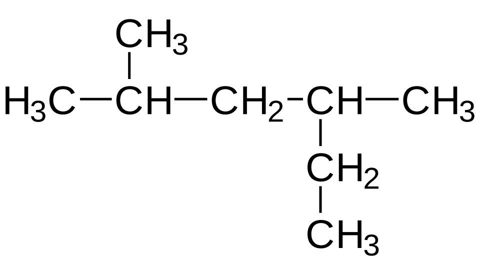
- **Isomerism**
  - two compounds with same chemical formula can have quite different structures/atomic arrangement

Ex: C_8H_{18}

- **n-octane**

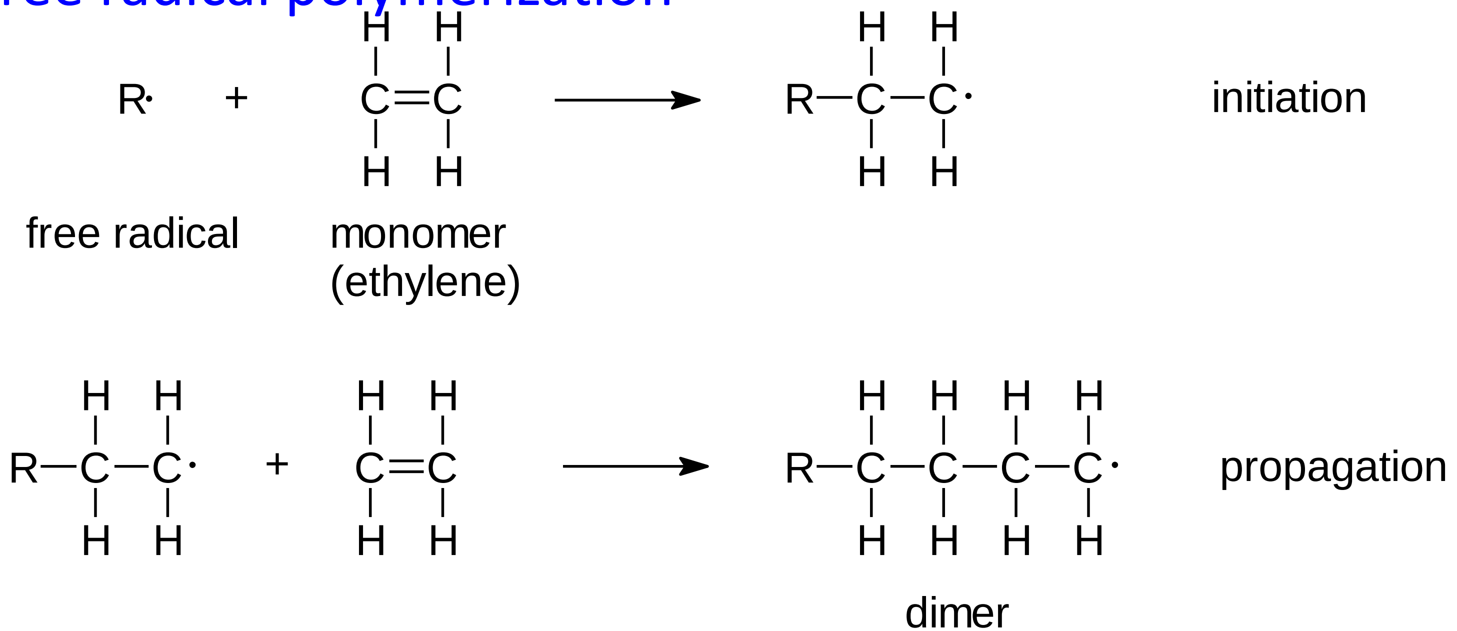


- **2-methyl-4-ethyl pentane (isooctane)**

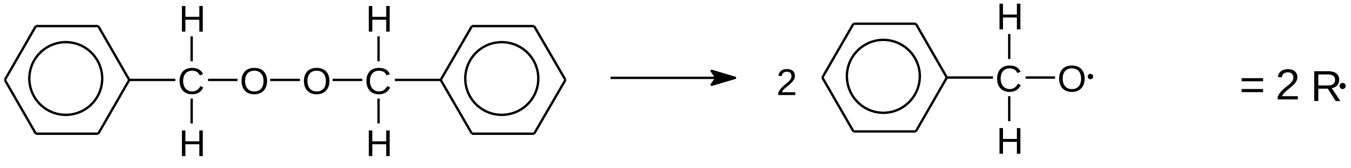


Chemistry of Polymers

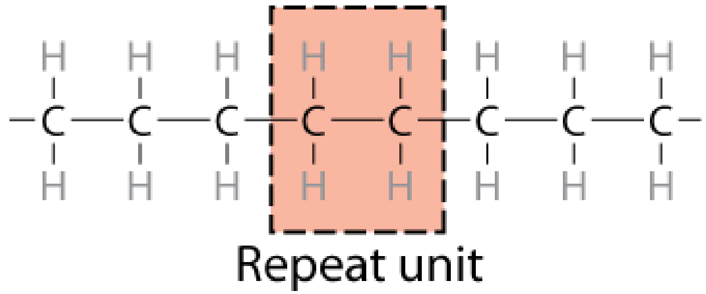
- Free radical polymerization



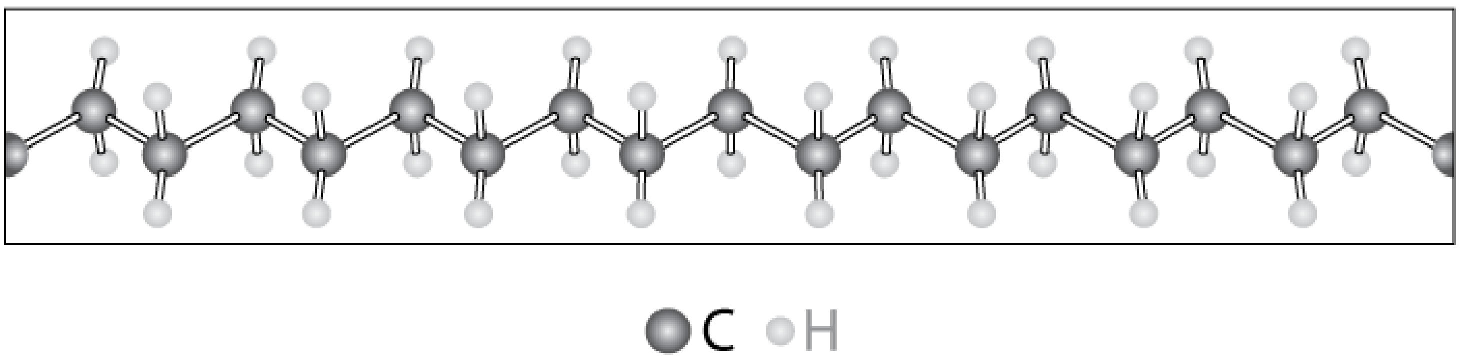
- Initiator: example - benzoyl peroxide



Chemistry of Polymers



Adapted from Fig. 14.1, *Callister 7e.*

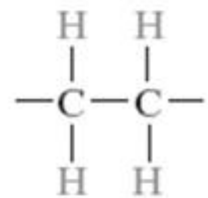
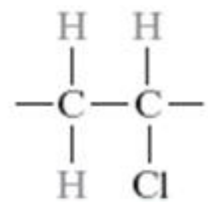
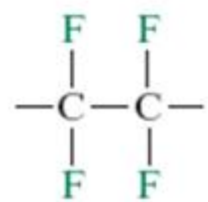
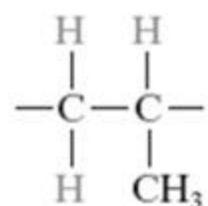


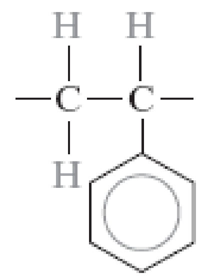
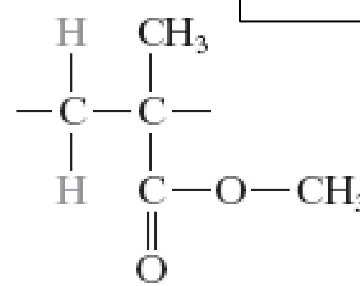
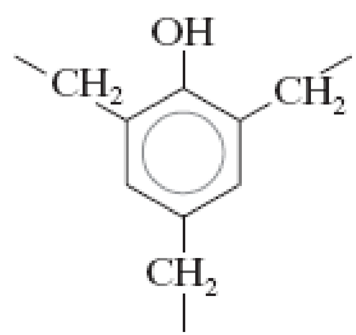
Note: polyethylene is just a long HC

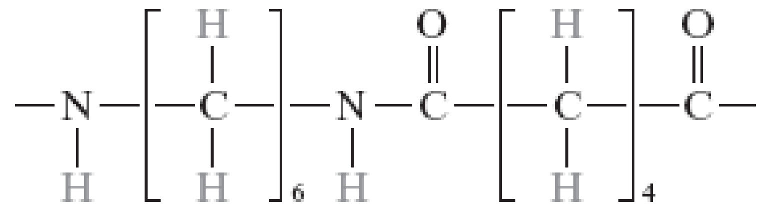
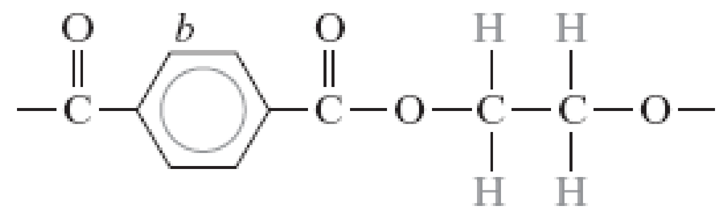
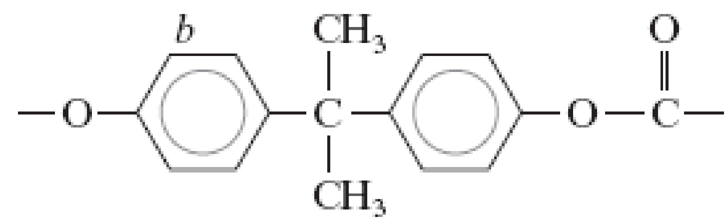
- paraffin is short polyethylene

Bulk or Commodity Polymers

Table 14.3 A Listing of Repeat Units for Polymeric Materials

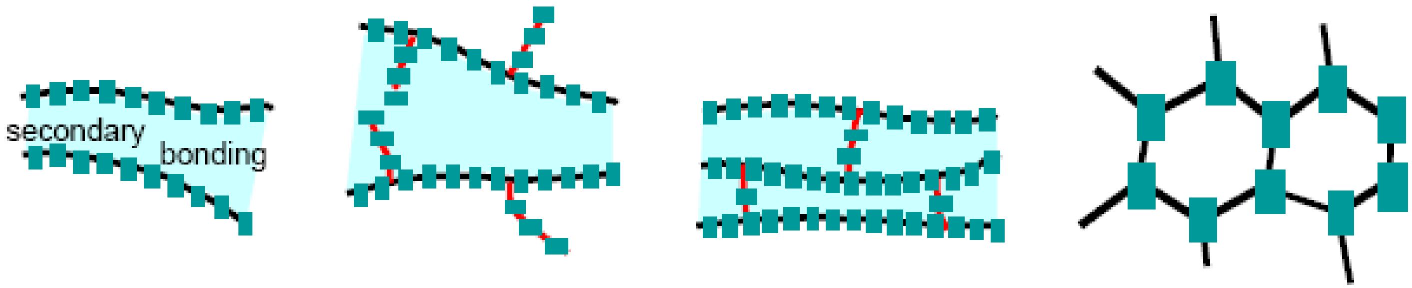
Polymer	*Repeat Unit*
Polyethylene (PE)	
Poly(vinyl chloride) (PVC)	
Polytetrafluoroethylene (PTFE)	
Polypropylene (PP)	

Polymer	*Repeat Unit*
Polystyrene (PS)	
Poly(methyl methacrylate) (PMMA)	
Phenol-formaldehyde (Bakelite)	

Polymer	Repeat Unit
Poly(hexamethylene adipamide) (nylon 6,6)	
Poly(ethylene terephthalate) (PET, a polyester)	
Polycarbonate (PC)	

Molecular Structures

- Covalent chain configurations and strength:



Linear | Branched | Cross-Linked | Network

Direction of increasing strength

Adapted from Fig. 14.7, *Callister 7e.*

Range of Polymers

- Traditionally, the industry has produced two main types of synthetic polymer – plastics and rubbers.
- Plastics are (generally) rigid materials at service temperatures
- Rubbers are flexible, low modulus materials which exhibit long-range elasticity.

Range of Polymers

- Plastics are further subdivided into thermoplastics and thermosets

Thermoplastics & Thermosetting polymers

- Thermoplastics polymers: soften when heated and harden when cooled and vice versa
- Structure Example: linear, branched:
- Polyethylene, polystyrene, PVC, Poly (ethylene terephthalate)
- Thermosetting polymers: permanently hard (do not soften when heated)
- Made from network polymers: covalent bond resist motion at high temperature prevent.
- Epoxies, phenolics, and some polyester resins.

Synthesis of Polymers

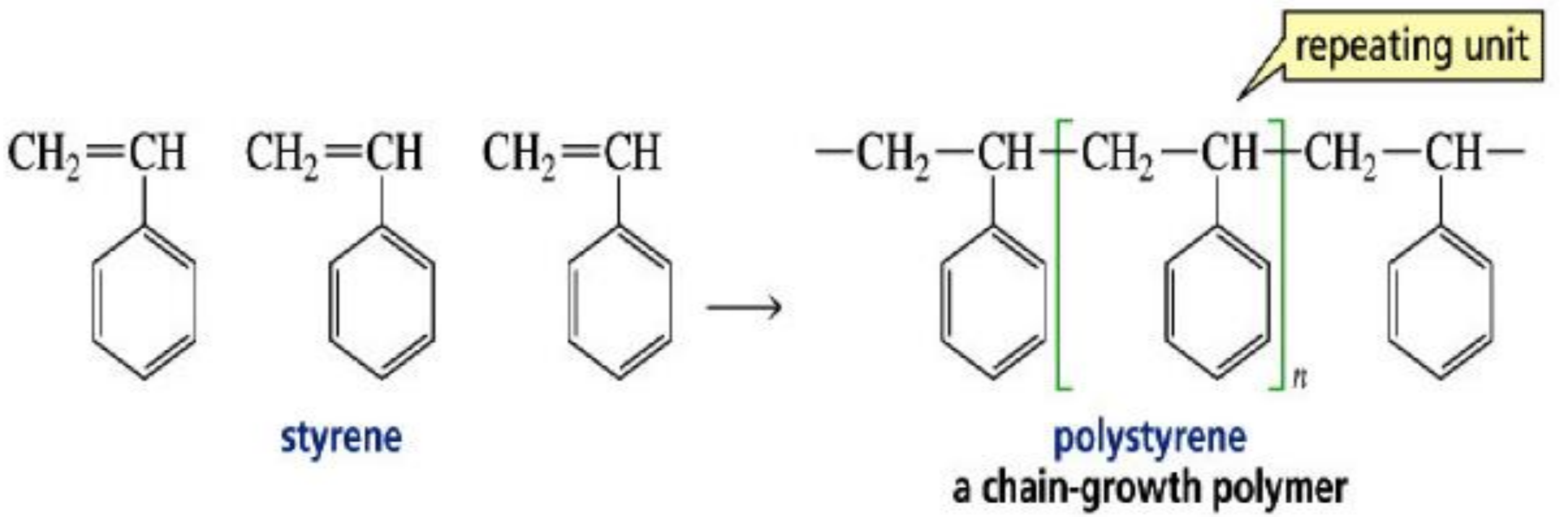
1

Synthesis of Polymers

- **There are a number different methods of preparing polymers from suitable monomers, these are**
  - **step-growth (or condensation) polymerisation**
  - **addition polymerisation**
  - **insertion polymerisation.**

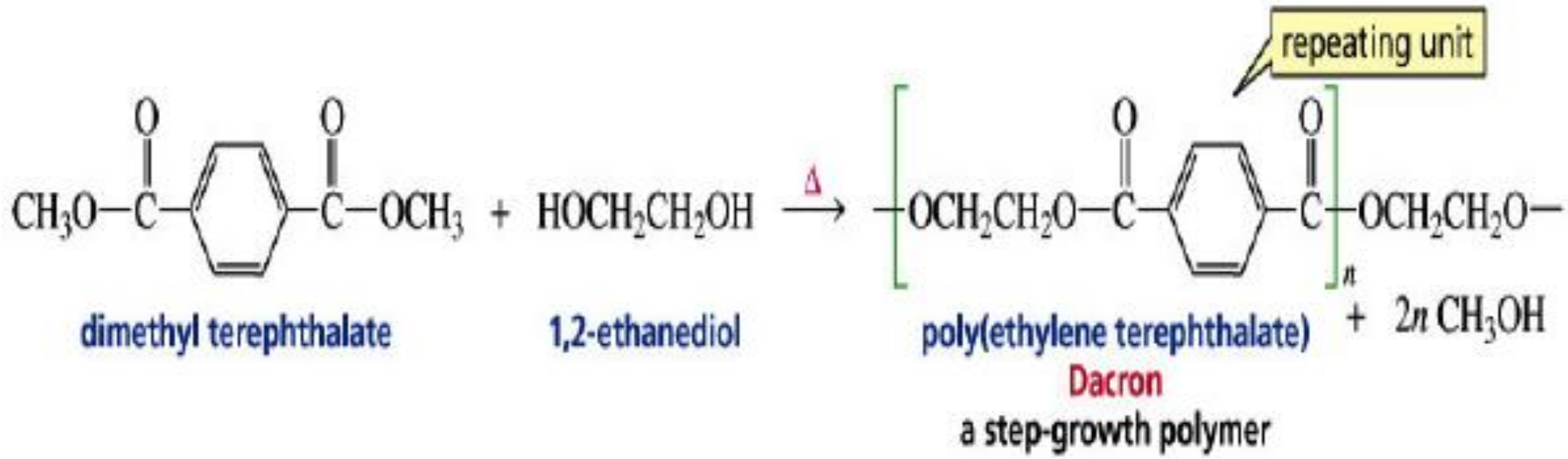
Types of Polymerization

- Chain-growth polymers, also known as addition polymers, are made by chain reactions



Types of Polymerization

- Step-growth polymers, also called condensation polymers, are made by combining two molecules by removing a small molecule



Addition Vs. Condensation Polymerization

- Polymerisation reactions can generally be written as

  x-mer + y-mer ⟶ (x +y)-mer

- In a reaction that leads to **condensation polymers**, x and y may assume any value
- i.e. chains of any size may react together as long as they are capped with the correct functional group

Types of Addition Polymerization

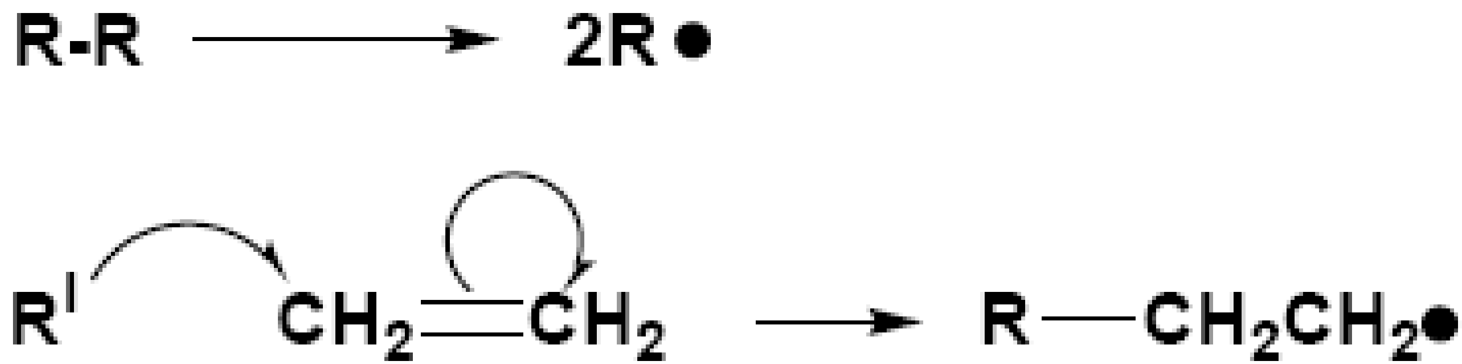
- Free Radical
- Cationic
- Anionic

Free Radical Polymerization

- Usually, many low molecular weight alkenes undergo rapid polymerization reactions when treated with small amounts of a radical initiator.
- For example, the polymerization of ethylene

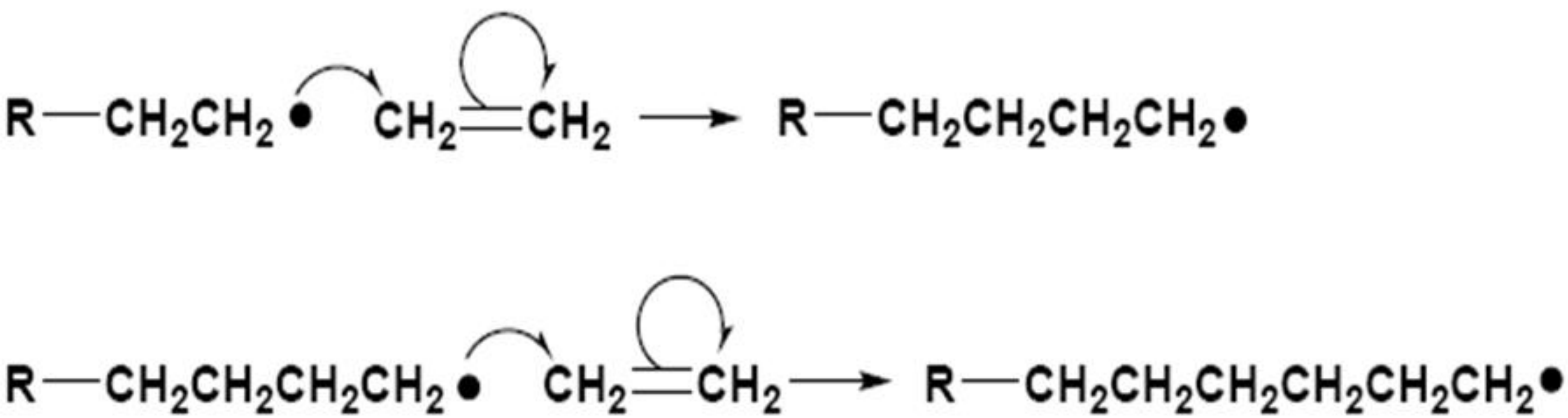
Free Radical Polymerization

step 1: Initiation



Free Radical Polymerization

step 2: Propagation



Free Radical Polymerization

step 3: Termination

$$2\,R-(CH_2CH_2)_nCH_2CH_2^{\bullet} \longrightarrow R-(CH_2CH_2)_nCH_2CH_2-CH_2CH_2(CH_2CH_2)_nR$$

$$2\,R-(CH_2CH_2)_nCH_2CH_2^{\bullet} \longrightarrow R-(CH_2CH_2)_nCH=CH_2 + R-(CH_2CH_2)_nCH_2CH_3$$

Ionic Polymerization

- Ionic polymerization is more complex than free-radical polymerization

Ionic Polymerization

- Whereas free radical polymerization is non-specific, the type of ionic polymerization procedure and catalysts depend on the nature of the substituent (R) on the vinyl (ethenyl) monomer.

Ionic Polymerization

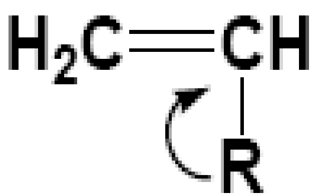
- Cationic initiation is therefore usually limited to the polymerization of monomers where the R group is electron-donating
- This helps stabilise the delocation of the positive charge through the p orbitals of the double bond

Ionic Polymerization

- Anionic initiation, requires the R group to be electron withdrawing in order to promote the formation of a stable carbanion (ie, -M and -I effects help stabilise the negative charge).

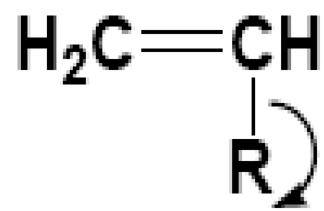
Ionic Polymerization

Cationic



R - Electron donating

Anionic



R - Electron withdrawing

Ionic Polymerization

(i) Initiation can occur in one of the four following ways:

(a) $$M + I^{\oplus} \longrightarrow MI^{\oplus}$$

Cationic

(b) $$M + I^{\ominus} \longrightarrow MI^{\ominus}$$

Anionic

(c) $$M + e^{\ominus} \longrightarrow M^{\ominus}$$

Anionic

(c) $$M - e^{\ominus} \longrightarrow M^{\oplus}$$

Cationic

Ionic Polymerization

- M is a Monomer Unit.
- As these ions are associated with a counter-ion or gegen-ion the solvent has important effects on the polymerization procedure.

Ionic Polymerization

(ii) Chain Propagation depends on :

- Ion separation
- The nature of the Solvent
- Nature of the counter Ion

Anionic Polymerization

- Involves the polymerization of monomers that have strong electron-withdrawing groups, eg, acrylonitrile, vinyl chloride, methyl methacrylate, styrene etc. The reactions can be initiated by methods (b) and (c) as shown in the sheet on ionic polymerization

Anionic Polymerization

- eg, for mechanism (b)

$$CX \longrightarrow C^{\oplus} + X^{\ominus}$$

$$X^{\ominus} + M \longrightarrow MX^{\ominus}$$

Anionic Polymerization

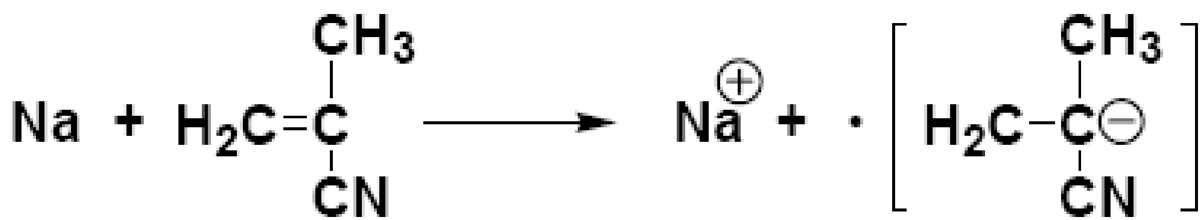
- The gegen-ion may be inorganic or organic and typical initiators include KNH2, n-BuLi, and Grignard reagents such as alkyl magnesium bromides

Anionic Polymerization

- If the monomer has only a weak electron-withdrawing group then a strong base initiator is required, eg, butyllithium; for strong electron-withdrawing groups only a weak base initiator is required, eg, a Grignard reagent.

Anionic Polymerization

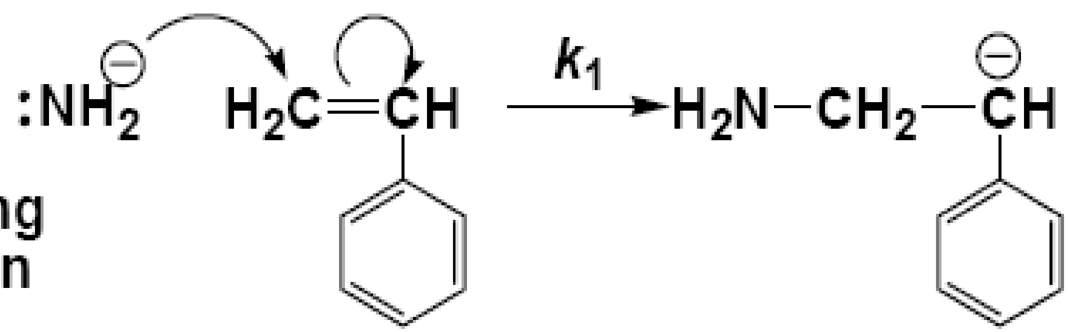
- Initiation mechanism (c) requires the direct transfer of an electron from the donor to the monomer in order to form a radical anion.
- This can be achieved by using an alkali metal eg.,



Anionic Polymerization of Styrene

(i) **Initiation**

$$KNH_2 \rightleftharpoons K^{\oplus} + :NH_2^{\ominus}$$

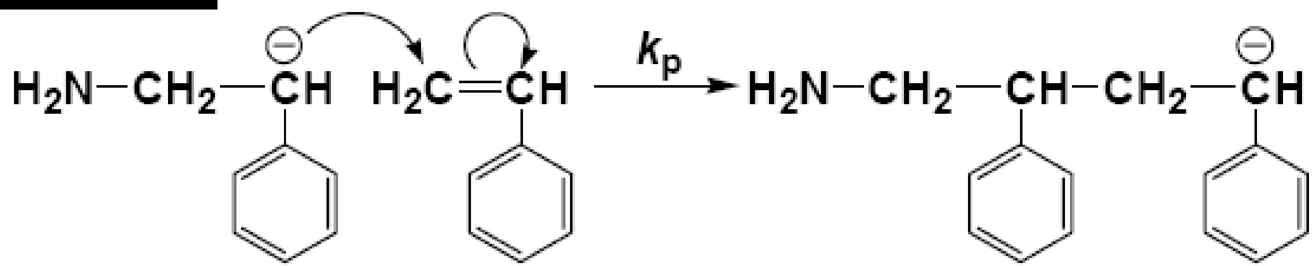


Rate determining step in initiation

Rate $v_1 = k_1[NH_2^{\ominus}][M]$

Anionic Polymerization of Styrene

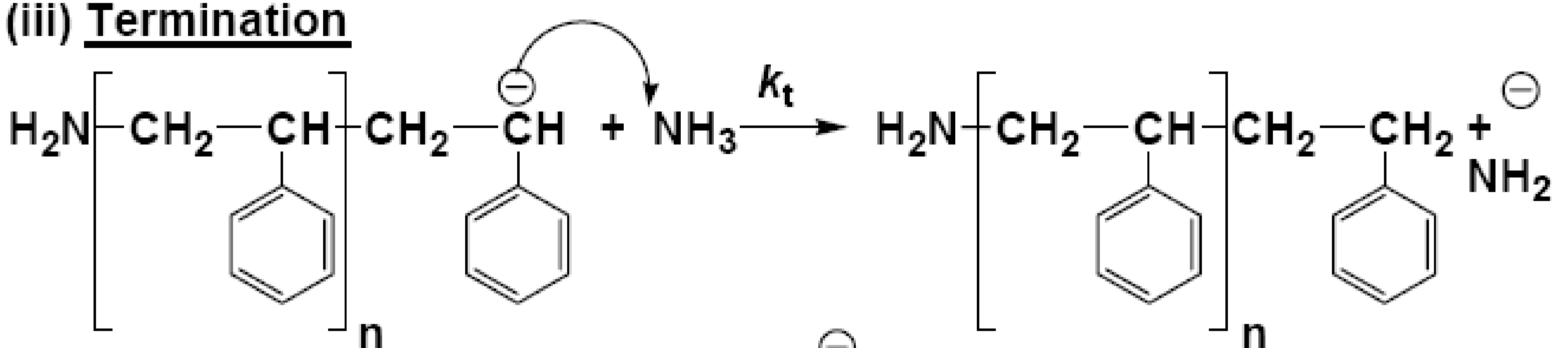
(ii) Propagation



Rate $v_p = k_p[M^{-}][M]$

Anionic Polymerization of Styrene

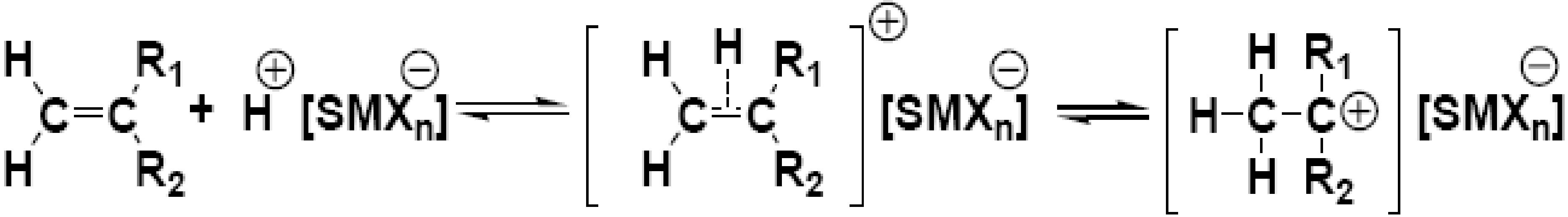
(iii) **Termination**



Rate $v_t = k_t[M^{\ominus}][NH_3]$

Cationic Polymerization

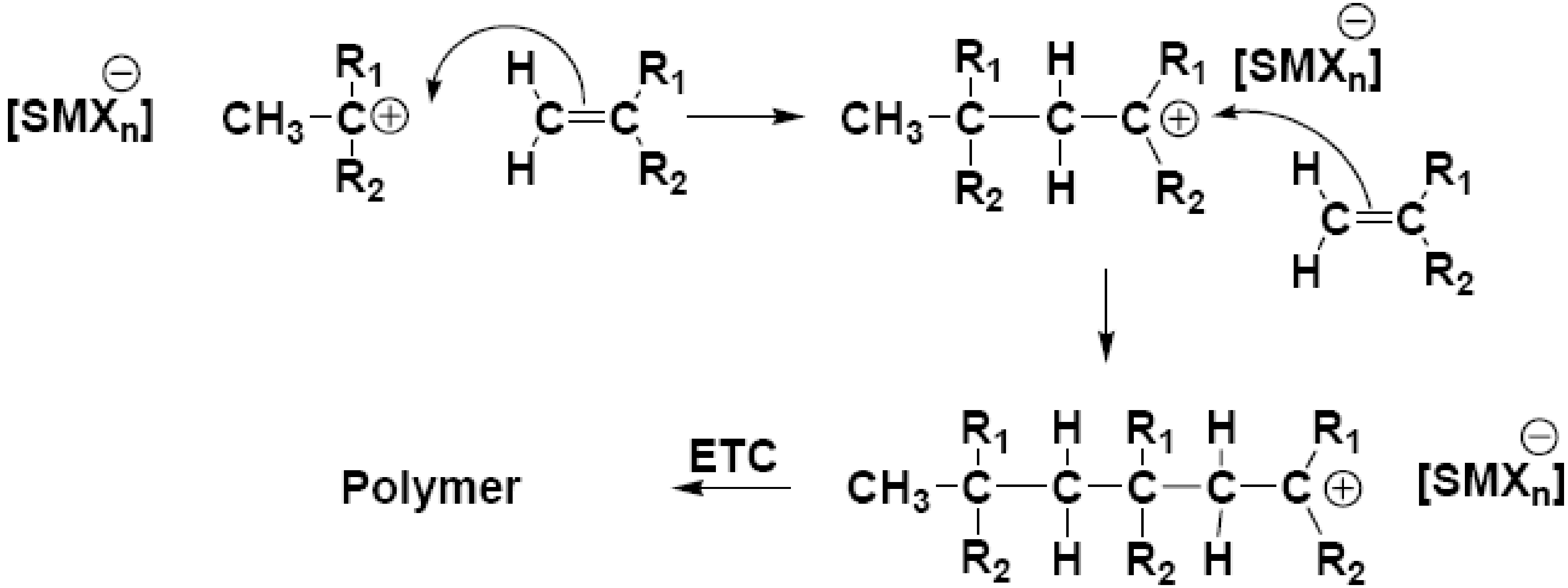
(i) <u>Initiation</u>



Cationic Polymerization

- (ii) PropagationChain growth takes place through the repeated addition of a monomer in a head-to-tail manner to the ion with retention of the ionic character throughout

Cationic Polymerization



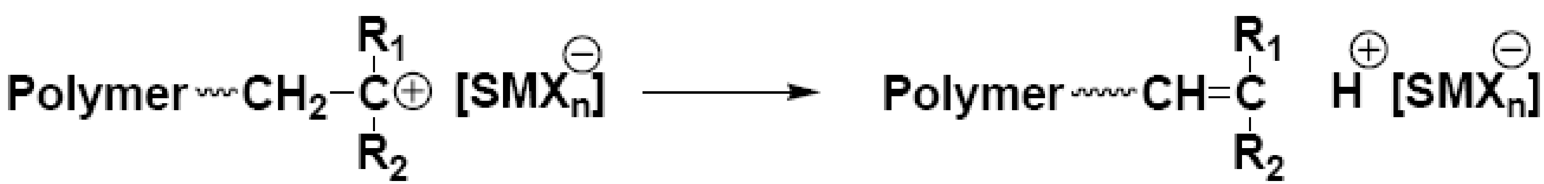
Cationic Polymerization

(iii) Termination

Termination of cationic polymerization reactions are less well-defined than in free-radical processes. Two possibilities exist as follows:

Cationic Polymerization

(a) Unimolecular rearrangement of the ion pair



Cationic Polymerization

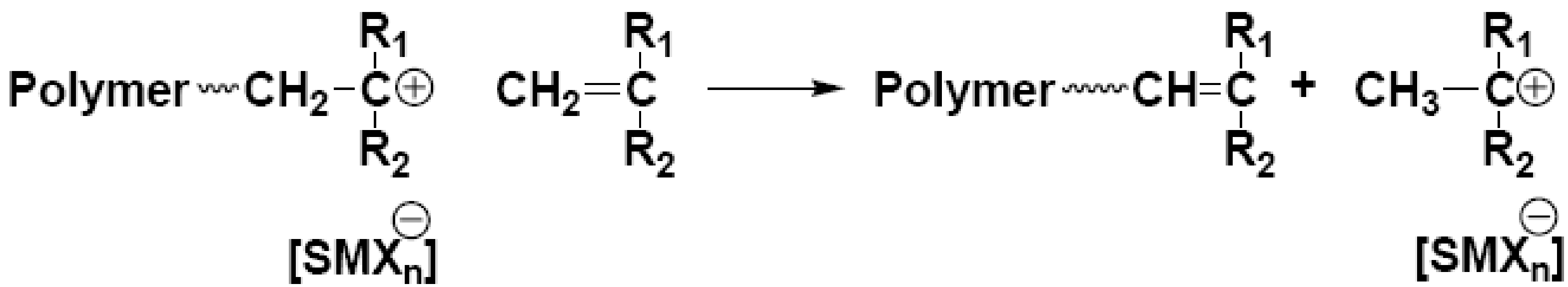
- Hydrogen abstraction occurs from the growing chain to regenerate the catalyst-co-catalyst complex.
- Covalent combination of the active centre with a catalyst-co-catalyst complex fragment may occur giving two inactive species.

Cationic Polymerization

- The kinetic chain is terminated and the initiator complex is reduced - a more effective route to reaction termination.

Cationic Polymerization

(b) <u>Bimolecular transfer reaction with the monomer</u>



Reformation of the monomer-initiator complex, ensuring that the kinetic chain is not terminated by the reaction.

Cationic Polymerization

- The kinetics of these reactions is not well understood, but they proceed very rapidly at extremely low temperatures.

Polymerization Techniques

These include:

- Bulk Polymerization
- Solution Polymerization
- Suspension Polymerization
- Emulsion Polymerization

Bulk Polymerization

Advantages:

- High yield per reactor volume
- Easy polymer recovery
- The option of casting the polymerisation mixture into final product form

Bulk Polymerization

Limitations:

- Difficulty in removing the last traces of monomer
- The problem of dissipating heat produced during the polymerization
  - In practice, heat dissipated during bulk polymerization can be improved by providing special baffles

Solution Polymerization

- **Definition:** A polymerization process in which the monomers and the polymerization initiators are dissolved in a nonmonomeric liquid solvent at the beginning of the polymerization reaction. The liquid is usually also a solvent for the resulting polymer or copolymer.

Solution Polymerization

- Heat removed during polymerization can be facilitated by conducting the polymerization in an organic solvent or water

Solution Polymerization

- Solvent Requirements:
- Both the initiator and the monomer be soluble in it
- The solvent have acceptable chain transfer characteristics and suitable melting and boiling points for the conditions of the polymerization and subsequent solvent-removal step.

Solution Polymerization

- Solvent choice may be influenced by other factors such as flash point, cost and toxicity
- Reactors are usually stainless steel or glass lined

Solution Polymerization

Disadvantages:

- small yield per reactor volume
- The requirements for a separate solvent recovery step

Suspension Polymerization

- **Definition:** A polymerization process in which the monomer, or mixture of monomers, is dispersed by mechanical agitation in a liquid phase, usually water, in which the monomer droplets are polymerized while they are dispersed by continuous agitation. Used primarily for PVC polymerization

Suspension Polymerization

- If the monomer is insoluble in water, bulk polymerization can be carried out in suspended droplets, i.e., monomer is mechanically dispersed.
- The water phase becomes the heat transfer medium.

Suspension Polymerization

- So the heat transfer is very good. In this system, the monomer must be either
  - 1) insoluble in water or
  - 2) only slightly soluble in water, so that when it polymerizes it becomes insoluble in water.

Suspension Polymerization

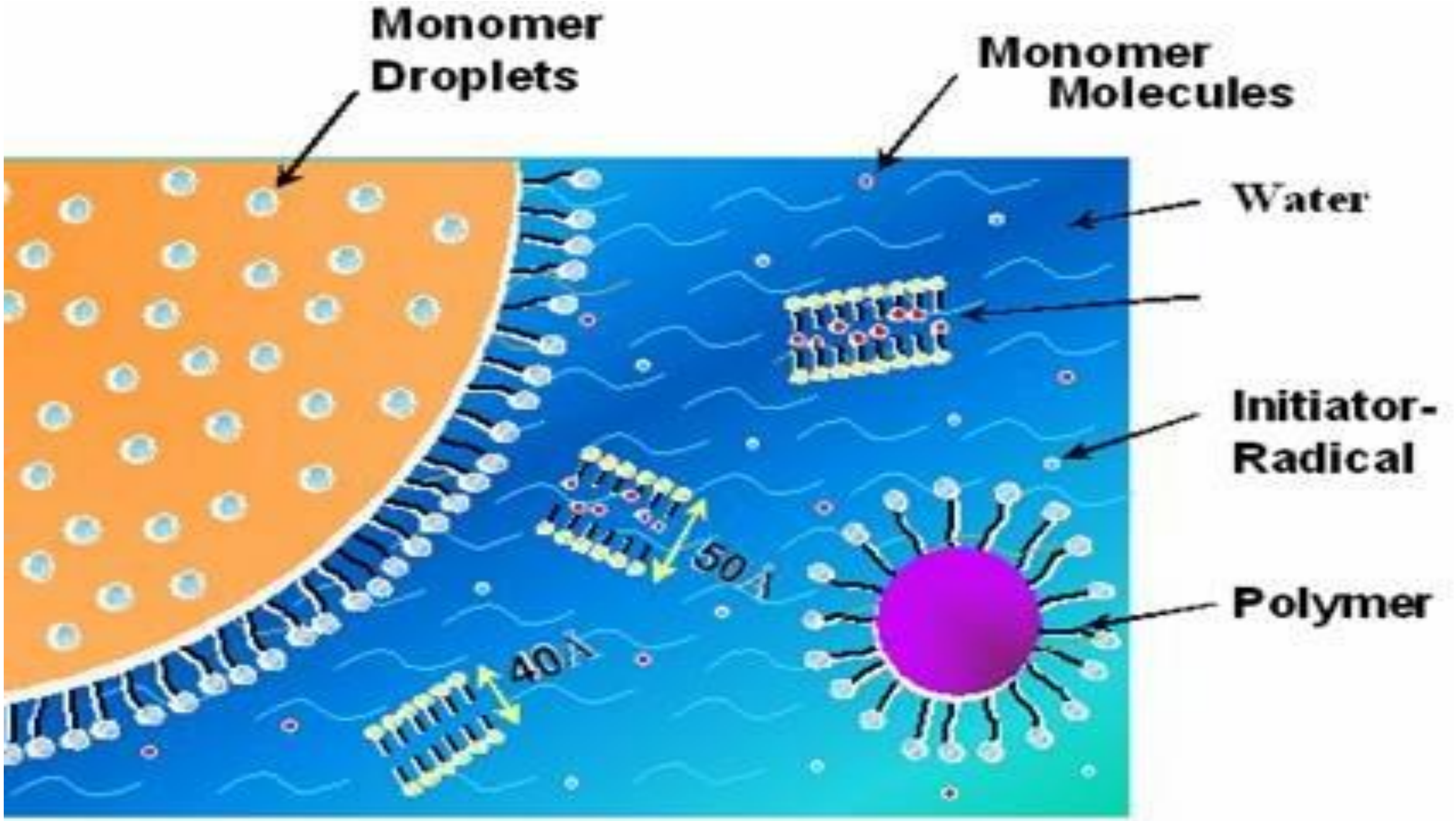
- The behavior inside the droplets is very much like the behavior of bulk polymerization
- Since the droplets are only 10 to 1000 microns in diameter, more rapid reaction rates can be tolerated (than would be the case for bulk polymerization) without boiling the monomer.

Emulsion Polymerization

- **Emulsion polymerization** is a type of radical polymerization that usually starts with an emulsion incorporating water, monomer, and surfactant.

Emulsion Polymerization

- The most common type of emulsion polymerization is an oil-in-water emulsion, in which droplets of monomer (the oil) are emulsified (with surfactants) in a continuous phase of water.
- Water-soluble polymers, such as certain polyvinyl alcohols or hydroxyethyl celluloses, can also be used to act as emulsifiers/stabilizers.



Emulsion Polymerization – Schematic

Emulsion Polymerization

Advantages of emulsion polymerization include:

- High molecular weight polymers can be made at fast polymerization rates. By contrast, in bulk and solution free radical polymerization, there is a tradeoff between molecular weight and polymerization rate.
- The continuous water phase is an excellent conductor of heat and allows the heat to be removed from the system, allowing many reaction methods to increase their rate.

Emulsion Polymerization

Advantages Continued:

- Since polymer molecules are contained within the particles, viscosity remains close to that of water and is not dependent on molecular weight.
- The final product can be used as is and does not generally need to be altered or processed.

Emulsion Polymerization

Disadvantages of emulsion polymerization include:

- For dry (isolated) polymers, water removal is an energy-intensive process
- Emulsion polymerizations are usually designed to operate at high conversion of monomer to polymer. This can result in significant chain transfer to polymer.