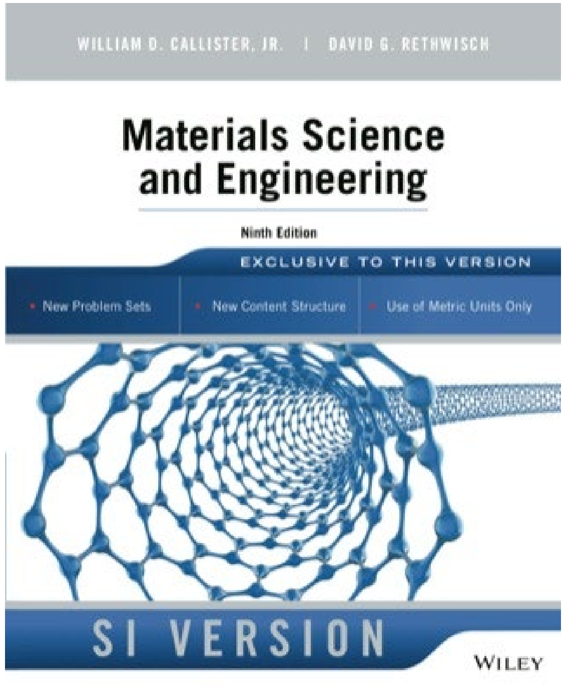
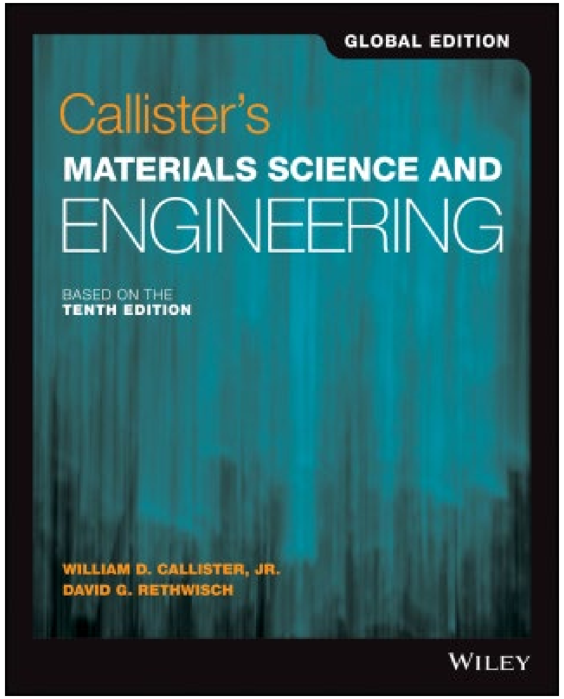
Materials Science A244
Week 2 - Lecture 2: Structure of Polymers

Stellenbosch UNIVERSITY IYUNIVESITHI UNIVERSITEIT | forward together sonke siya phambili saam vorentoe



← Callister 9th ed	Topics	Callister 10th ed →
5.1 – 5.8	Molecular considerations	14.1 – 14.8
5.9 – 5.10	Types of polymers	14.9 – 14.10
5.11	Polymer crystals	14.12

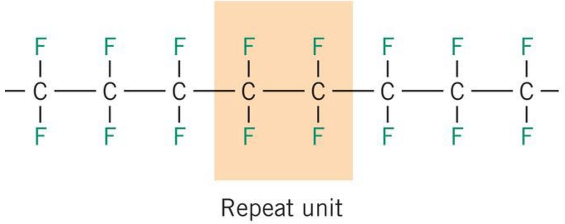
Note: 4.13 9th / 14.13 10th Polymer crystallinity is covered in Week 2, Lecture 1



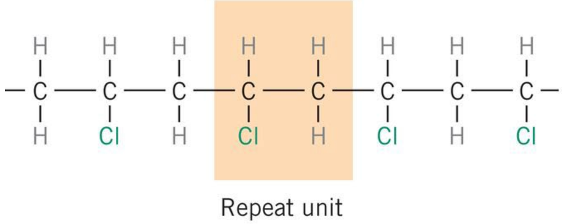
Prof Deborah Blaine
Mechanical & Mechatronics Engineering

What is a polymer?

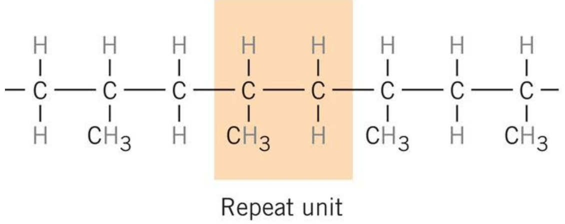
Greek *poly*- many, -*mer* parts: molecular chains of repeating units



(a)

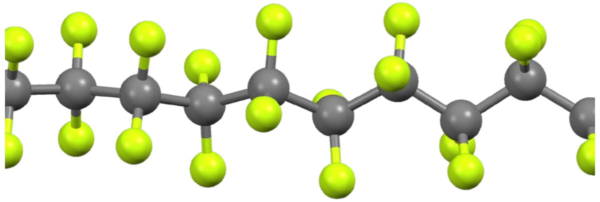


(b)

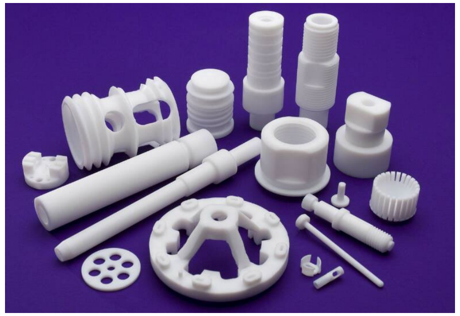


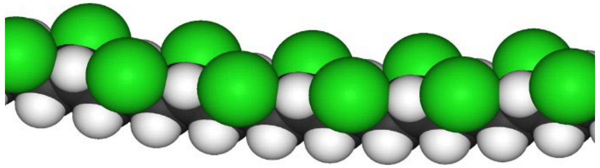
(c)

Poly(tetrafluroethene) – PTFE - Teflon®


Source: Wikipedia

Ball-and-stick model of a perfluorodecyl chain, $-C_{10}F_{21}$

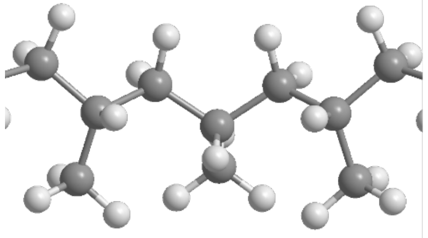

Source: PTFE machinery


Source: Wikipedia

Space-filling model of a part of a PVC chain

Polyvinyl chloride - PVC


Source: Indiamart


Source: Wikipedia

Ball-and-stick model of polypropylene

Polypropylene - PP

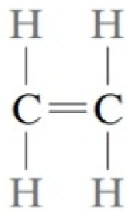

Source: Adreco plastics

Hydrocarbons (Koolwaterstowwe)

Most polymers are organic, many organic materials are hydrocarbons (C + H)

Saturated (all single bonds)

Unsaturated

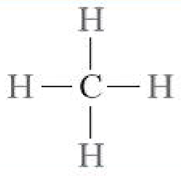
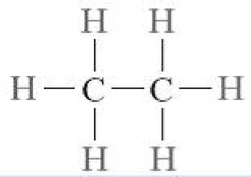
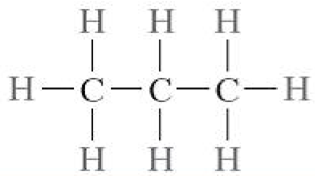


Ethylene – carbon double bond

H—C≡C—H

Acetylene – carbon triple bond

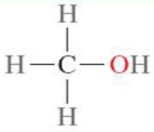
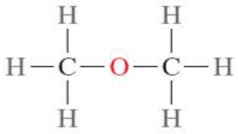
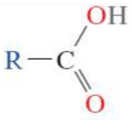
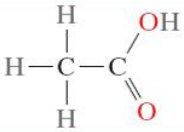
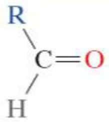
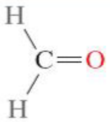
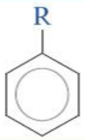
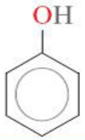
Table 5.1 Compositions and Molecular Structures for Some Paraffin Compounds: C_nH_{2n+2}

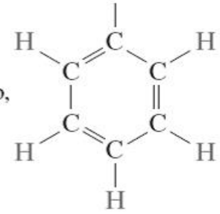
Name	*Composition*	*Structure*	*Boiling Point (°C)*
Methane	CH_4		−164
Ethane	C_2H_6		−88.6
Propane	C_3H_8		−42.1
Butane	C_4H_{10}		−0.5
Pentane	C_5H_{12}		36.1
Hexane	C_6H_{14}		69.0

Callister 9th 5.2 / 10th 14.2

Hydrocarbons (Koolwaterstowwe)

Table 5.2
Some Common Hydrocarbon Groups

Family	*Characteristic Unit*		*Representative Compound*
Alcohols	R—OH		Methyl alcohol
Ethers	R—O—R′		Dimethyl ether
Acids			Acetic acid
Aldehydes			Formaldehyde
Aromatic hydrocarbons[a]			Phenol

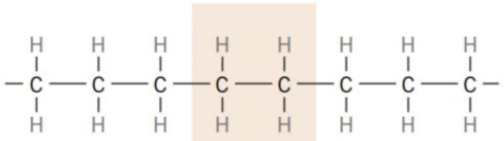
[a]The simplified structure  denotes a phenyl group, 

Callister 9th 5.2 / 10th 14.2

Polymers and their chemistry

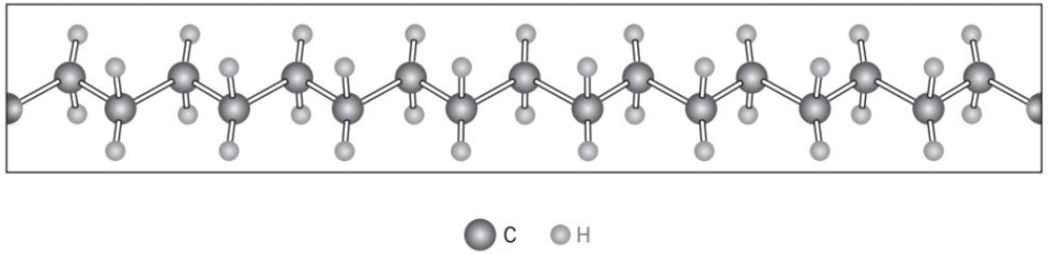
- Polymers are huge molecules, *macromolecules*, compared to hydrocarbon molecule.
- They are synthesized from a small molecule, the *monomer,* and made up of repeating units, *mers*, of this monomer.

By example: Polyethylene (PE)



Repeat unit

(a)

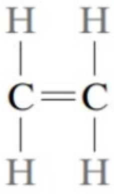


(b)

Monomer

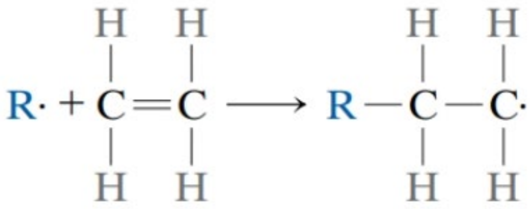
Ethylene C_2H_4

Gas at RT



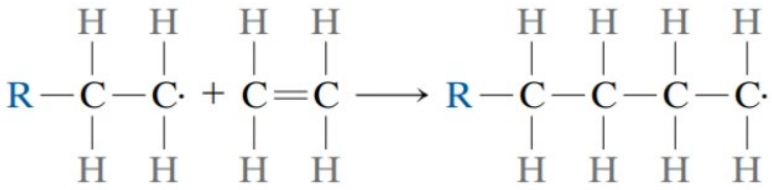
Initiation reaction

Initiator (R) reacts with ethylene



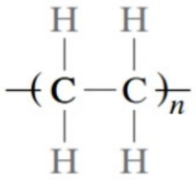
Addition reaction

Additional ethylene groups added to chain



Polymer chain

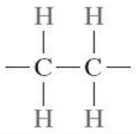
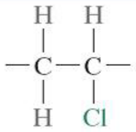
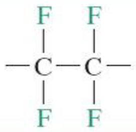
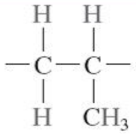
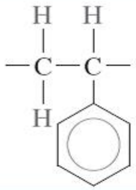
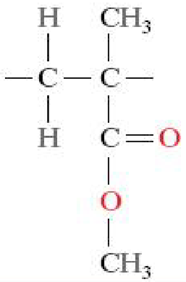
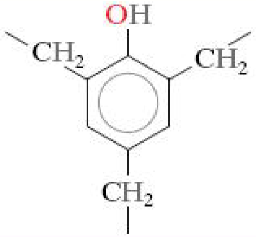
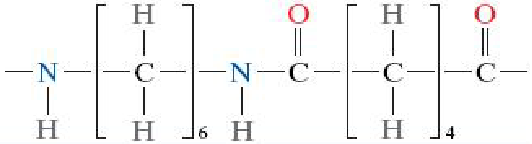
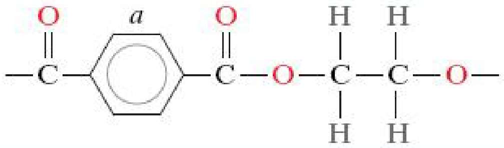
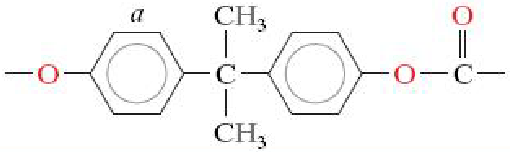
Polyethylene

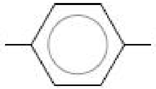
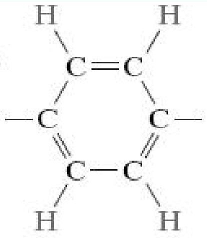


Callister 9th 5.3 – 5.4 / 10th 14.3 – 14.4

Common polymers

Table 5.3 Repeat Units for Ten of the More Common Polymeric Materials

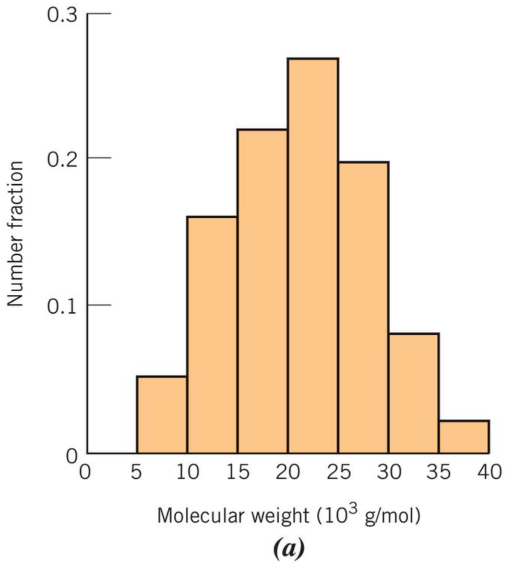
Polymer	*Repeat Unit*
Polyethylene (PE)	
Poly(vinyl chloride) (PVC)	
Polytetrafluoroethylene (PTFE)	
Polypropylene (PP)	
Polystyrene (PS)	
Poly(methyl methacrylate) (PMMA)	
Phenol-formaldehyde (Bakelite)	
Poly(hexamethylene adipamide) (nylon 6,6)	
Poly(ethylene terephthalate) (PET, a polyester)	
Polycarbonate (PC)	

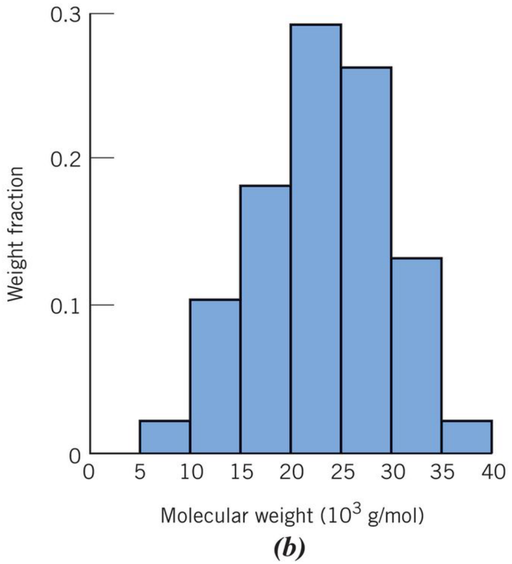
[a] The  symbol in the backbone chain denotes an aromatic ring as 

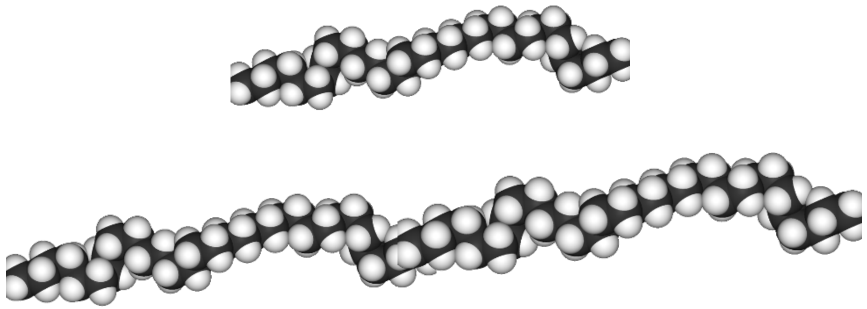
Callister 9th 5.4 / 10th 14.4

Molecular weight & Degree of polymerization

- Polymers are made up of many molecular chains; each chain has a different length and therefore different mass







Degree of polymerization is the average number of repeating units in a molecular or polymer chain

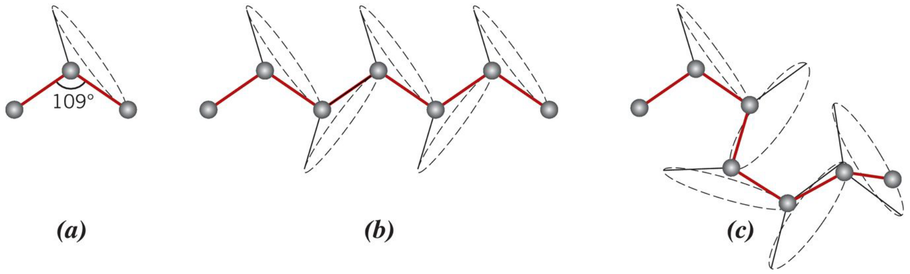
Molecular weight is the average mass of all the chains in a polymer, weighted by count (number) or by mass (weight)

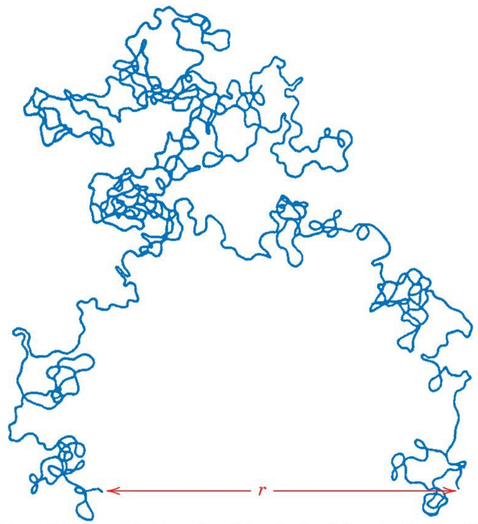
Both these parameters give an indication of the **average size** of the polymer or molecular chains in a polymer.

Callister 9th 5.5 / 10th 14.5

Molecular shape

- Molecular chains are not straight; they can bend, twist and rotate around their backbone chain atoms.
- Polymers consist of large numbers of molecular chains, each of which may bend, coil, and kink
- The end-to-end distance, r, of the polymer is much shorter than the actual molecular chain length (along the twists and turns)
- Bulky side groups inhibit the twists and turns of a polymer chain.



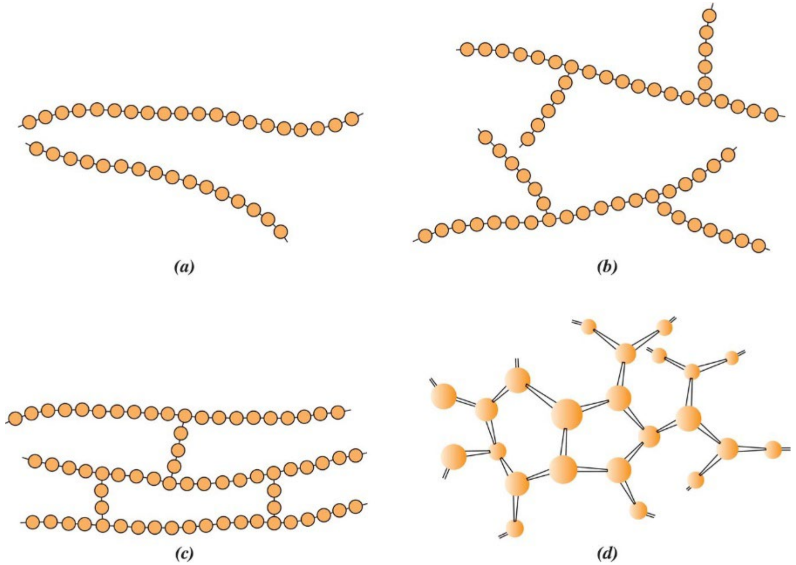


From Physics of Rubber Elasticity, 2nd edition, by Treloar (1958), Fig. 3.3, p. 47. By permission of Oxford University Press.

Callister 9th 5.6 / 10th 14.6

Molecular structure and configuration

Linear polymers
- repeat units are joined together end to end in single chains.
- Flexible
- Examples: HDPE, PVC, PMMA, Nylon (PA)

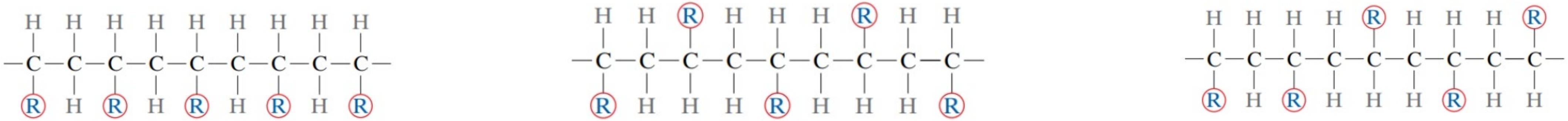


Branched polymers
- side-branch chains are connected to the main chain
- Side-branches influence packing
- Examples: LDPE

Crosslinked polymers
- adjacent linear chains are joined one to another at various positions by covalent bonds
- Many rubbers are cross-linked, called vulcanisation

Network polymers
- Three-dimensional networks of covalent bonds
- Examples: epoxies, poly- urethanes, and phenol-formaldehyde

Different atomic configurations are possible for the same composition: this is called **isomerism**.



Callister 9th 5.7 – 5.8 / 10th 14.7 – 14.8

Thermoplastic and Thermosetting polymers

Thermoplastic	Thermoset
Soften when heated, harden when cooled	Burn or decompose when heated
Repeatable and reversible process	Become permanently hard when they form (cure)
Mostly linear polymers, may have some branching	Mostly network polymers, some cross-linked
Ductile, easy to form	Hard and strong, dimensional stability
Examples: PE, polystyrene, PVC	Examples: vulcanised rubber, epoxies, polyester resin

Lego blocks are made from the thermoplastic polymer acrylonitrile butadiene styrene (ABS) by injection moulding

Photos: Murrayplastics.com, Ampa Plastics Group

Source: acrylgiessen.com

Polyester resin, a thermosetting polymer, is painted on to fibre glass, where it sets to create a polymer matrix composite.

Callister 9th 5.9 10th 14.9

Copolymers: two or more monomers polymerised together

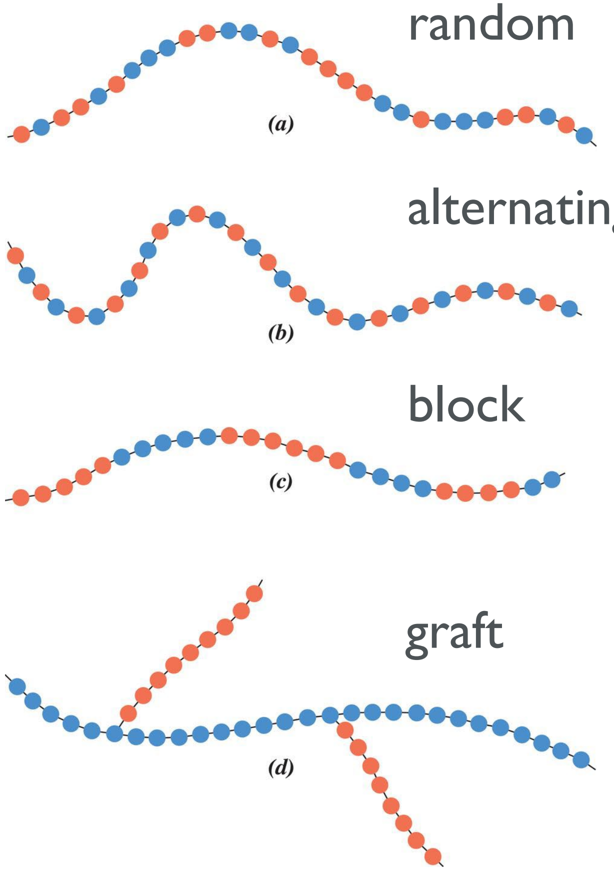
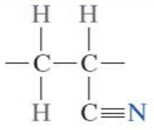
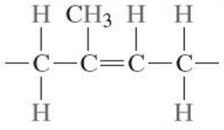
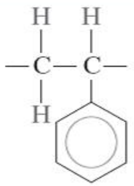
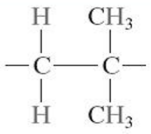
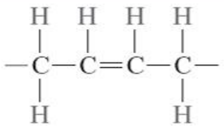
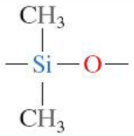
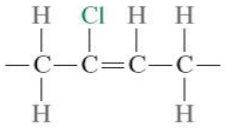
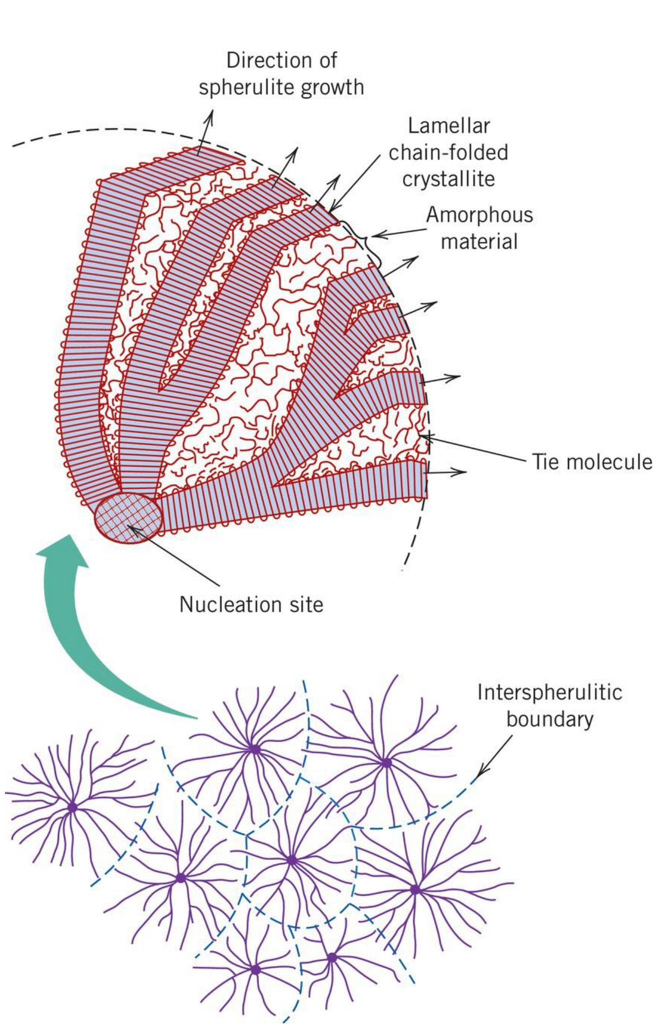
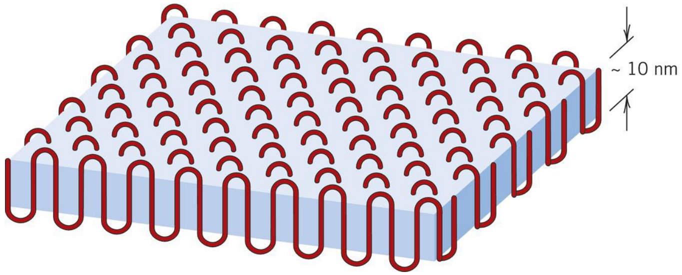


Table 5.5 Chemical Repeat Units That Are Employed in Copolymer Rubbers

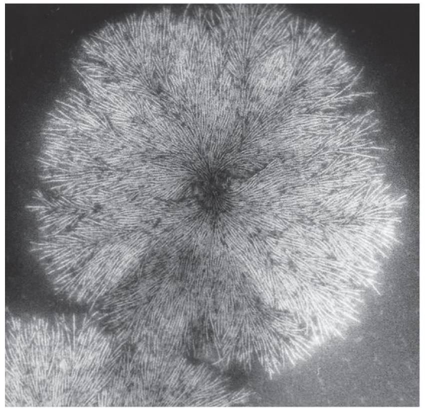
Repeat Unit Name	*Repeat Unit Structure*	*Repeat Unit Name*	*Repeat Unit Structure*
VMSE Repeat Units for Rubbers — Acrylonitrile		VMSE — Isoprene	
VMSE — Styrene		VMSE — Isobutylene	
VMSE — Butadiene		VMSE — Dimethylsiloxane	
VMSE — Chloroprene			

Polymer Crystals





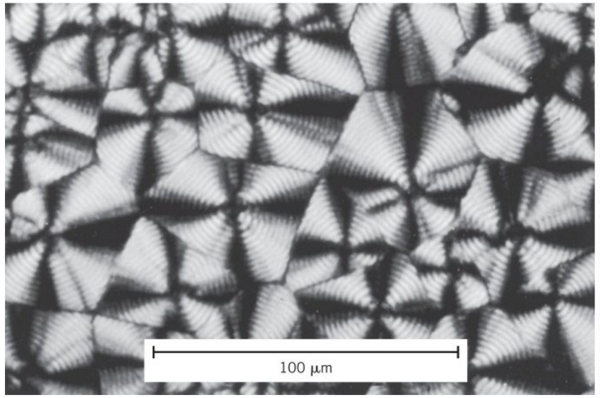
Rubber spherulite



(d)

Photograph of Figure (d) supplied by P. J. Phillips. First published in R. Bartnikas and R. M. Eichhorn, Engineering Dielectrics, Vol. IIA, Electrical Properties of Solid Insulating Materials: Molecular Structure and Electrical Behavior, 1983. Copyright ASTM, 1916 Race Street, Philadelphia, PA 19103. Reprinted with permission.

Crystalites: small crystalline regions of chain-folded lamellae
Spherulite: Spherical structure of crystallites emanating from a nucleation site at the core with amorphous regions in between crystalites



Courtesy F. P. Price, General Electric Company

Polyethylene spherulites

Callister 9th 5.11 / 10th 14.11

Thank you | Dankie | Enkosi

Stellenbosch
UNIVERSITY
IYUNIVESITHI
UNIVERSITEIT
forward together
sonke siya phambili
saam vorentoe

COPYRIGHT

DISCLAIMER

This content is provided without warranty or representation of any kind. The use of the content is entirely at your own risk and Stellenbosch University (SU) will have no liability directly or indirectly as a result of this content.

The content must not be assumed to provide complete coverage of the particular study material. Content may be removed or changed without notice.

The video is of a recording with very limited post-recording editing. The video is intended for use only by SU students enrolled in the particular module.