An Introduction to Polymer Physics

Wentao Hao
College of Chemical Engineering
Hefei University of Technology

2. Short Range Structure of Polymer Chains（近程结构）

2.1 brief introduction **4 hours**

Why & What

1. Why learn polymer structure?

Polymer physics ⇔ **structure** ⇕ **motion** ⇕ **properties**

2. What're the features?

① **Chain-like**
② **Flexibility**
③ **Diversity**
④ **Complicated Condensed State Structure**

Where are the examples?

3. The 4 levels of polymer structure

- **1st level**
- **2nd level**

→ About one single polymer chain → **chain structure**

- **3rd level**
- **4th level**

→ About a flock of polymer chains → **condensed state structure**

(a) 1st order structure

- **The short range structure**
  - **chemical composition （组成）**
  - **Architecture（构造）**
  - **Configuration（构型）**
  - **sequential structure of copolymers （序列结构）**
- **Microstructure of one single chain**

(b) 2nd order structure

- The long range structure
  - Size（尺寸）
  - Shape（形状）
  - flexibility of molecules（柔性）
- Morphology of one single chain

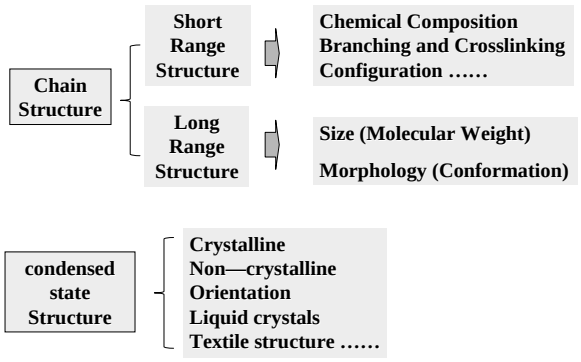
(c) 3rd order structure

- crystalline phase structure（晶相结构）
- non-crystalline phase structure（非晶相结构）
- oriented phase structure（取向结构）
- liquid phase structure（液晶结构）
- Corresponding to a flock of chains

(d) 4th order structure

- textile phase structure（织态结构）
- Composed of third order structures

Key point



高分子链结构

近程结构
- 化学组成
- 单体单元键合单个高分子链的键接（交联与支化）
- 单体单元主体构型（空间排列）

远程结构
- 高分子的大小（分子量）
- 高分子的形态（构象）

高分子聚集态结构
- 晶态
- 非晶态
- 取向态
- 液晶态
- 织态

2.2 short range structure of polymer chains

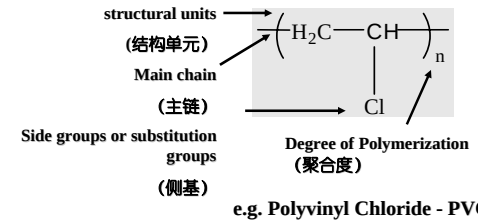
- Do you remember what is the short range structure?
- Composition
- Branching and crosslinking
- Sequential of structural units
- Configuration

Where are the examples?

What's the chemical composition?

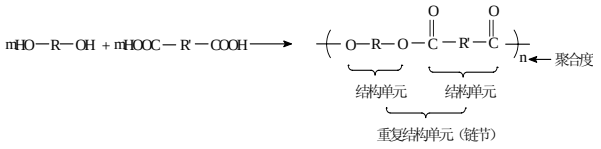
- **Polymer chain structure is linear, such a concept was proposed and confirmed by Staudinger et al in 1920's -1930's**
- **Polymer chains are always obtained by *addition reaction* or *condensation reaction***

Addition Reactions



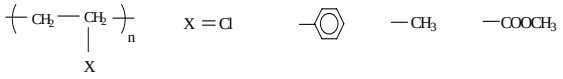
e.g. Polyvinyl Chloride - PVC

Condensation Reactions



Carbon Chain Polymers

polymer chain is composed of carbons linked by covalent bonds (most of them are obtained by addition reaction), for example:



These polymers are difficult to be hydrolyzed. In addition, they are easy processing, are flammable, are easily aged and not heat-durable.

BESIDES CARBON CHAIN POLYMERS

Heterochain polymer
杂链高分子

Elementary chain polymer
元素高分子

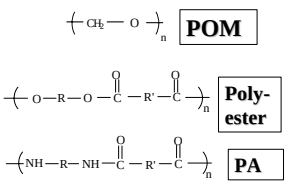
Elementary Organic polymer
元素有机高分子

Elementary Inorganic polymer无机高分子

Due to the different structures, the properties of polymers are not the same.

Hetero-chain polymers

- **backbones are composed of carbon atoms and other atoms like O, S, N etc**



POM

Poly-ester

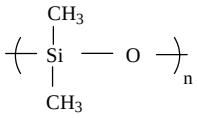
PA

they are easy to be decomposed by water, alcohol or acids, but are heat-durable and strong

Most of them are used as engineering plastics.

Elementary chain polymer

- **backbones are composed of non-carbon atoms, like** Si, P, Al, Ti, As, Sb, Ge



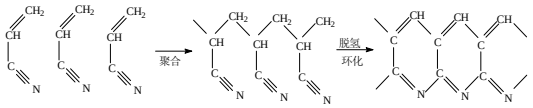
PDMS

Silicon rubber

▪ **Features: they are thermal stable, like inorganic compounds; but are also of elasticity and plasticity, like organic compounds; usually they are weak in mechanical properties**

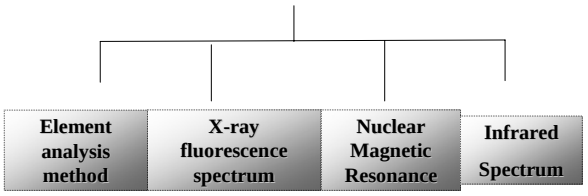
Ladder polymer

- **Molecular chain is not a single chain, but like "ladder" or "double helix"**



features: thermal stable.

Physical techniques for observation of the composition of polymer*

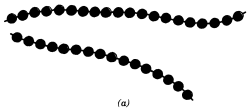


元素分析　X-射线荧光色谱　核磁共振　红外光谱

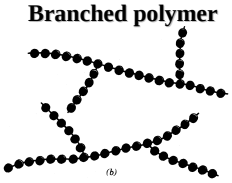
*高聚物的结构与性能, P10

What are branching and crosslinking?

Linear polymer chain

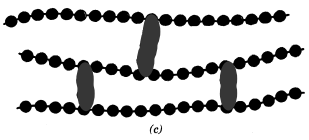


Branched polymer



Can be melted or dissolved

Crosslinked or network polymer



Can not be melted or dissolved

Table 2.1 Comparison of different Polyethylene*

	Low density PE	High density PE	Crosslinked PE
Density (g/cm^3)	0.91-0.94	0.95-0.97	0.95-1.40
Crystallinity (%) by X-ray detection	60-70	95	-
Melting point (ºC)	105	135	-
Tensile strength (MPa)	7-15	10-20	20-40
Upper using temperature	80-100	120	135
Application	Soft plastic products, thin films	Hard plastic products, pipe, sticks	Cables, electric equipments

*高聚物的结构与性能, P25

Physical techniques for analyzing branched and crosslinked polymers*

- **Infrared Spectrum**
- **Nuclear Magnetic Resonance**
- **Raman Spectrum**

***高聚物的结构与性能, P27**

What's the sequential structure of copolymers

- **Copolymer may contain two or more monomer units**

- **-A-B-A-B-A-B-A-B- alternating（交替）copolymer**
- **-A-A-A-B-B-B-B-B- block（嵌段） copolymer**
- **-A-B-A-A-B-B-B-A- random （无规）copolymer**
- **-A-A-A-A-A-A-A-A- grafting （接枝）copolymer**

B B
B B
B B
B B
B

Experimental methods to analyze sequential structure of copolymers*

- **Infrared Spectrum** 红外光谱
- **Nuclear Magnetic Resonance** 核磁共振

***高聚物的结构与性能, P29-37**

What is configuration?

Why it is a Key Point?

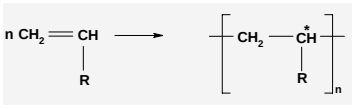
Configuration is refer to the arrangement of atoms fixed by the chemical bonds in molecules.

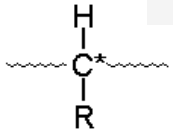
构型 是指分子中由化学键所固定的原子在空间的排列。

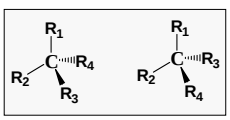
Same polymer, different configuration

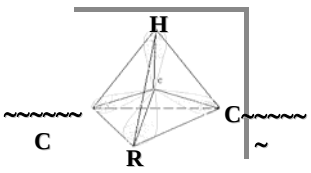
- **Optical isomerism** 旋光异构
- **Geometrical isomerism** 几何异构
- **Bonding manner isomerism** 键接异构

A. Optical isomerism 旋光异构







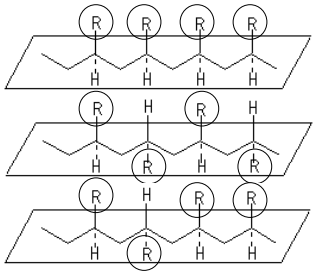


旋光异构高分子是否必定有旋光性？

内、外消旋作用，所以无旋光性; 但有些生物高分子和特殊结构的高分子具有旋光性

对高分子来说，关心不是具体构型(左旋或右旋)，而是构型在分子链中的异同，即全同(等规)、间同或无规。

3 kinds of isomers

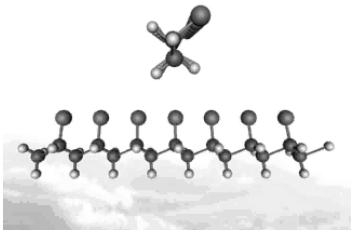


Isotactic
全同立构

Syndiotactic
间同立构

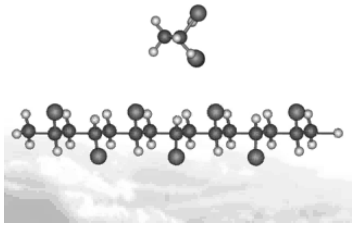
Atactic
无规立构

全同和间同立构聚合物统称为有规立构聚合物



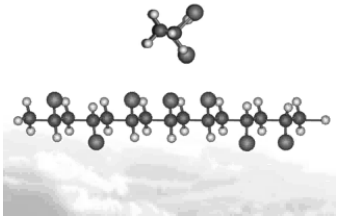
- **高分子全部由一种旋光异构单元键接而成。**
- **X基团处于分子平面的同一侧。**
- **分子链结构规整，可结晶。**
- **-D-D-D-D-D- or –L-L-L-L-L-**

Isotactic



- **两种旋光异构单元交替键接而成。**
- **X基团交替分布于分子平面两侧。**
- **分子链结构规整，可结晶。**
- **-D-L-D-L-D-L-D-L-D-L-D-L-**

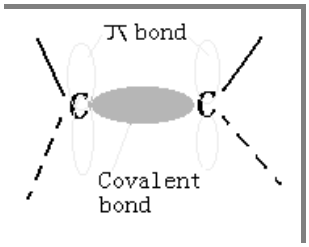
Syndiotactic



- **两种旋光异构单元无规键接而成。**
- **x基团无规分布于分子平面两侧。**
- **分子链结构不规整，不能结晶。**
- **-D-L-D-L-L-L-D-D-**

atactic

B. Geometrical isomerism

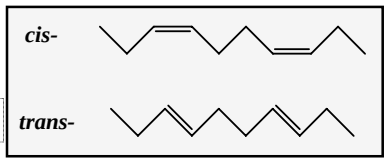


Double bonds on the main chain

Poly(1,4-butadiene)

cis-顺式

trans-反式



In Latin, *trans* means “on the other side” ;

and *cis* in Latin means “on the same side”

聚异戊二烯

Polyisoprene

顺式构型

Cis

反式构型

Trans

What kind of isomerism can be obtained for polyisoprene in 1, 2 addition?

C. Bonding manner isomerism

1,2 addition

head-to-tail

1,1 addition

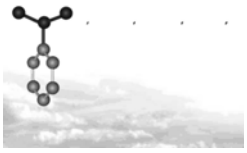
head-to-head or tail-to-tail

Random head to tail

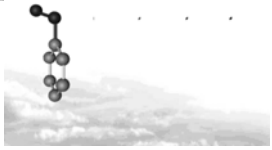
In general, polymers are like to be linked in head-to-tail manner.

(why?)

Head to tail



Head to head or tail to tail



Possible configuration of divinyl polymer

Q1. Which kind of isomer they are for the following polymers?

(1) —D—D—D—D—D—D—D—

(2) —L—L—L—L—L—L—L—

(3) —D—L—D—L—D—L—D—L—

(4) —D—D—L—D—L—L—L—

Answer: (1) isotactic; (2) isotactic; (3) syndiotactic; (4) atactic

Q2. Propylene oxide (环氧丙烷) can form different isomers through ring-open reaction, try to illustrate their structures

Poly (propylene oxide)/PPO

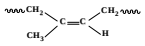
Due to the chiral C atoms, the structure of PPO will be

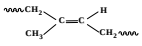
isotactic

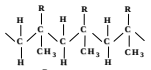
syndiotactic

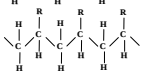
atactic

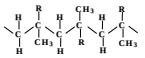
Q3. Isomers of polyisoprene

1) **Cis** 1,4 

2) **Trans** 1,4 

3) 1,2-isotactic 

4) 3,4-isotactic 

5) 1,2-syndiotactic 

6) 3,4-syndiotactic