

EMAC 276

Lecture 10 : The Polyolefin Family

Polyethylene – PE: Part 2: LDPE and HDPE

Polypropylene - PP

Poly(1-butene) – Polybutylene – PB

Andy Olah, Ph.D.

February 12, 2025

EMAC 276 - Homework Assignment #2

Due: Friday, February 14, 2025

Dr. Olah

During our classes we identified several common polymers that when initially discovered were described as “value-less”, “impossible to process”, “a useless mass”, etc. We also identified several methods (“tricks”) that were subsequently utilized to develop these polymers into successful products; many which are still with us today.

Your exercise is to select one polymer (either from our in-class discussion or from outside our class discussion) and describe 1) the polymer and the initial performance deficiency, 2) the action taken to overcome this deficiency, and, 3) the ensuing product(s) developed from this modification.

If you choose to use an “in class” example your maximum score will be 10.

If you choose to use an “outside the class” example your maximum score will be 12. (i.e., final score +2)

Your answer shall be short comprising between one-half to one page.

Your answer is shall be structured accordingly:

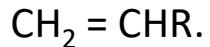
Paragraph #1: Identify and describe the polymer and it's initial deficiency **(3 Points)**

Paragraph #2: Identify the modification or “trick” which was utilized to overcome this deficiency. **(5 Points)**

Paragraph #3: Identify the commercial product or products resulting from this modification. **(2 Points)**

What is a “Olefin” Type Polymer?

Vinyl polymers are the most common type of polymers derived from “vinyl-type” monomers having the general structure:



Where,

polystyrene – R = C₆H₅

polyvinyl chloride – R = Cl

polyvinyl acetate – R = O₂CCH₃

polyacrylonitrile - R = CN

Not to be confused with poly(vinyl chloride) (PVC) materials which have traditionally been identified as “Vinyls”; i.e., vinyl siding, vinyl records, etc.

Olefin polymers are a subgroup of vinyl monomers produced from alkenes having a C_nH_{2n} monomer structure:

polyethylene – R = H => CH₂ = CH₂; (n = 2) => C₂H₄

polypropylene – R = CH₃ => CH₂ = CH-CH₃; (n = 3) => C₃H₆

polybutylene – R = CH₂-CH₃ => CH₂ = CH-CH₂-CH₃; (n=4) => C₄H₈

GLASSY TRANSITIONS IN SEMICRYSTALLINE POLYMERS

RAYMOND F. BOYER

*The Dow Chemical Company, Midland, Michigan 48640**

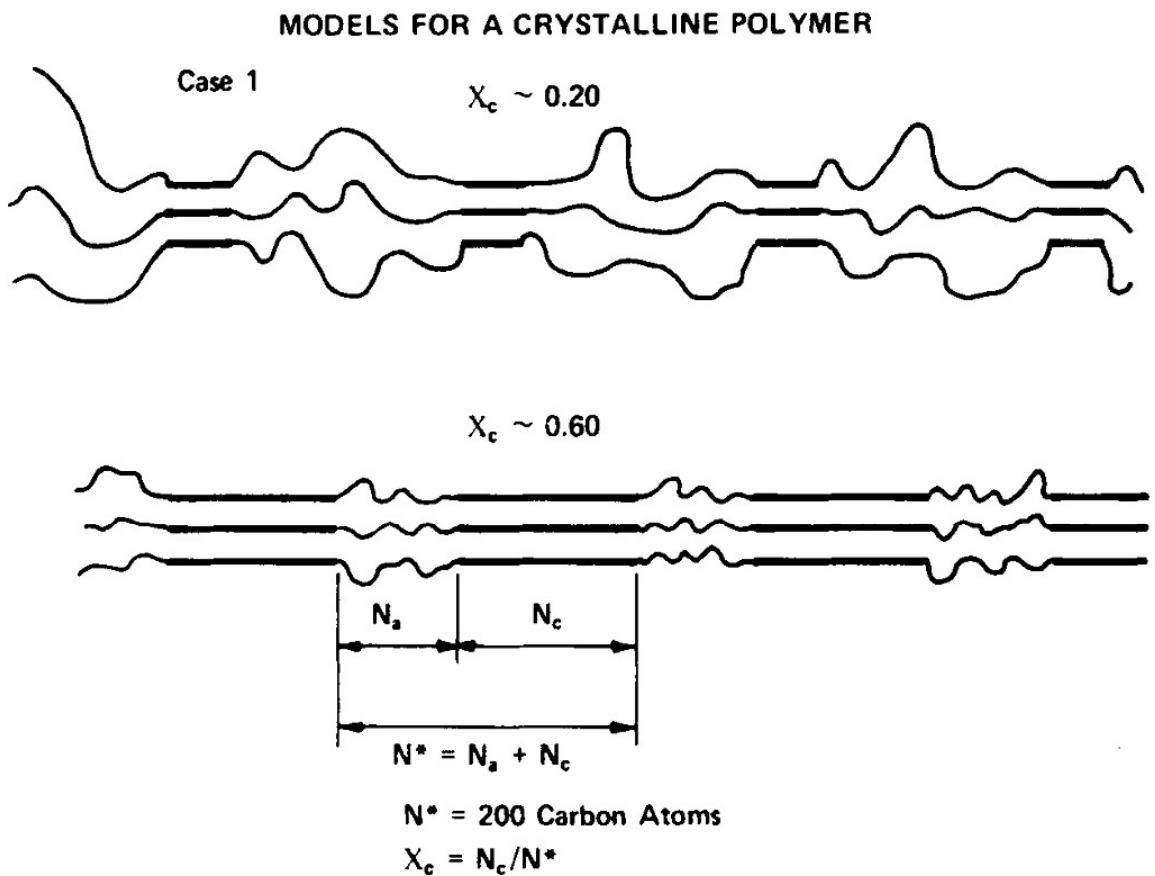


FIG. 13. Fringed micelle model used for calculating effect of crystallinity, x_c , on the intensity of T_g and $T < T_g$ peaks. N_a and N_c are the number of chain atoms in the amorphous and crystalline regions respectively. Very high mol wt is assumed.

Critical Properties for the Differentiation of the Polyethylene Types

Density

Crystalline Region

Perfect 1.00 g/cm³

Unit Cell Calculation (orthorhombic) 0.996

Single Crystal Determination 0.972

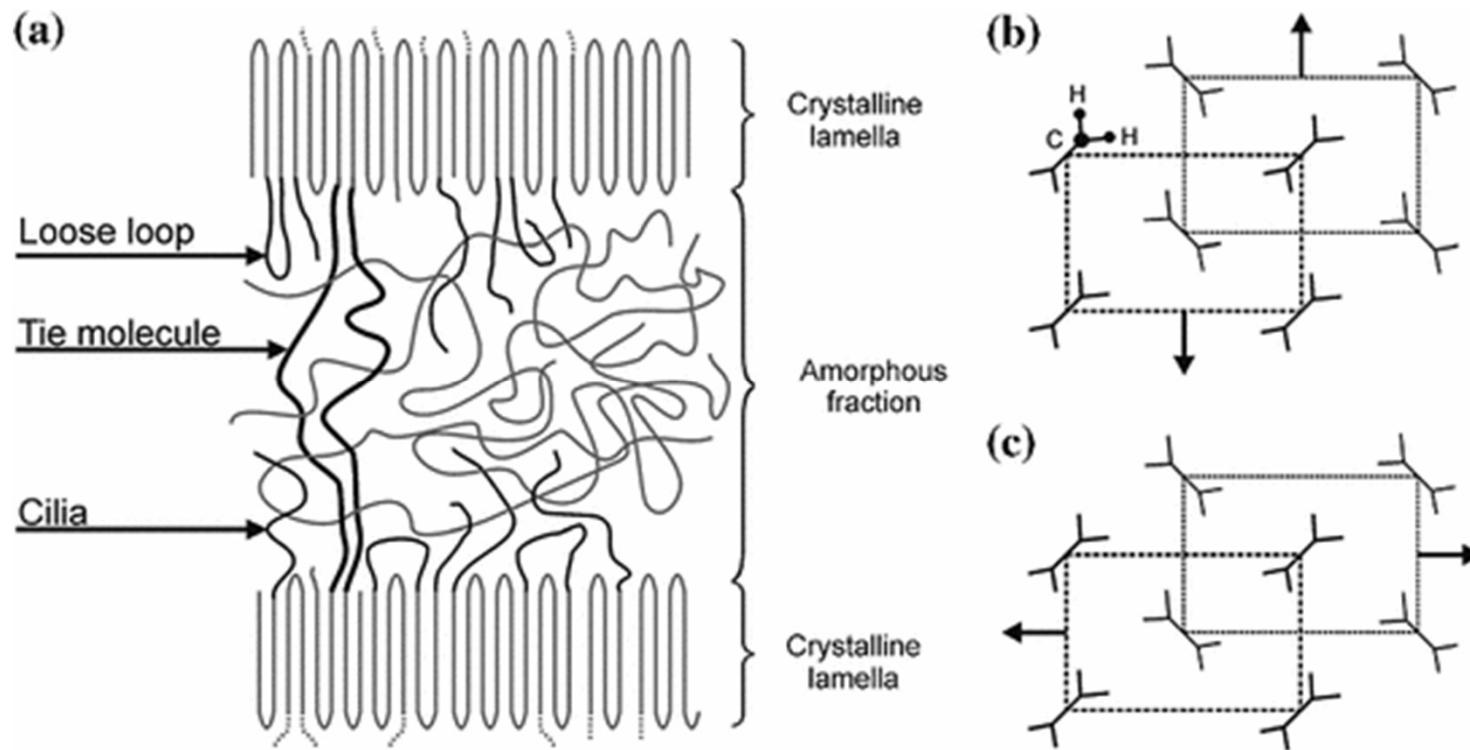
Amorphous Region 0.850 – 0.855

Transition Temperatures

Glass Transition Temperature **-78 C (195 K)**

Melt Transition Temperature (density dependent) 130-140 C

The Interlamellar and Interspherulitic Regions are the Amorphous Regions of Polyethylene



Boyer proposed that there exists two glass transition temperatures for polyethylene.

Glass Temperatures of Polyethylene

Raymond F. Boyer

The Dow Chemical Company, Midland, Michigan 48640. Received July 3, 1972

Macromolecules, 6, 288 – 299 (1973)

J. Poly., Sci., Symposium No. 50, 189 – 242 (1975)

"Linear and branched polyethylenes, especially in the Range of 50 – 75% crystallinity,, exhibit three amorphous Phase transitions or relaxation phenomena at the following temperature regions: 145 ± 10 K (-128 ± 10 C), 195 ± 10 K (-78 ± 10 C) and 240 ± 20 K (-33 ± 20 C)."

"Each of these regions has one or more characteristics of a true glass transition, i.e., an abrupt increase in the Coefficient of thermal expansion, and an abrupt increase in the specific heat; a dynamic mechanical loss peak Whose magnitude increases with amorphous content; . . ."

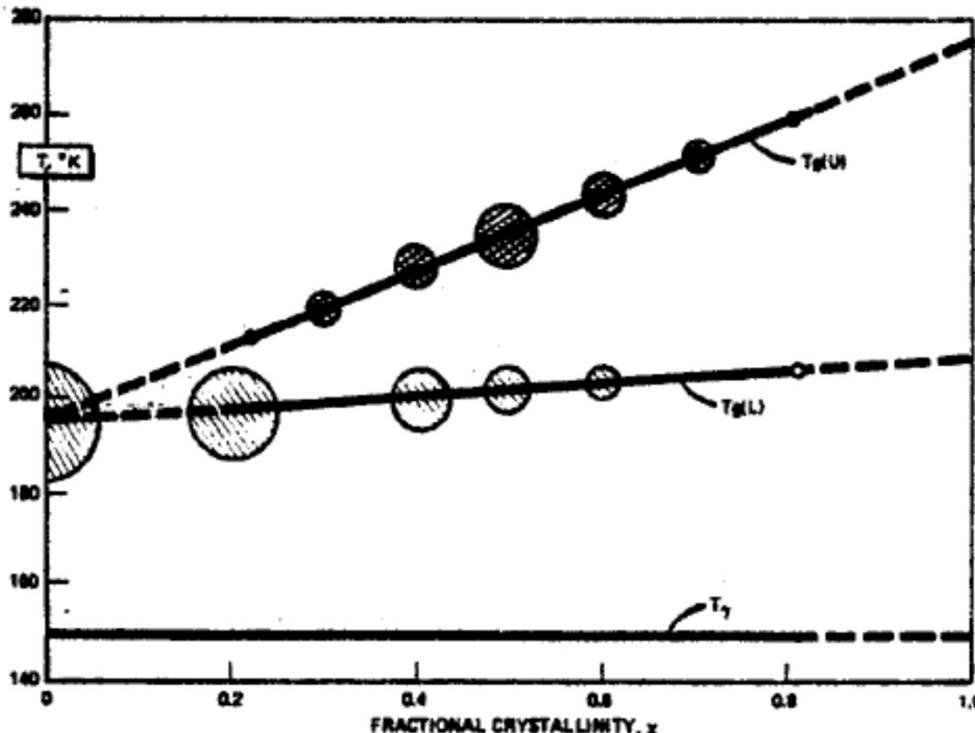


Figure 1. The double glass transition, $T_g(L)$ and $T_g(U)$, and the T_γ amorphous relaxation in linear polyethylene. The size of the circles indicate the intensity of the two glass transitions. Intensity of the T_γ transition increases continuously to the left. We associate $T_g(L)$ with cilia and polymer chains rejected by crystallites; and $T_g(U)$ with loose loops and/or tie molecules. This plot has been estimated by us from the thermal expansion data of Stehling and Mandelkern.²

Proposed Origin of $T_g(L)$ and $T_g(U)$

(4) Partially crystalline polyethylenes exhibit two glass transitions: a $T_g(L)$ around 195 K (-78 C) and a $T_g(U)$ around 240 K (-33 C) but both increase linearly with crystallinity. (5) These are ascribed to the existence of two types of amorphous material. For example, $T_g(L)$ may be associated with cilia and $T_g(U)$ may arise from loose loops and or tie molecules.

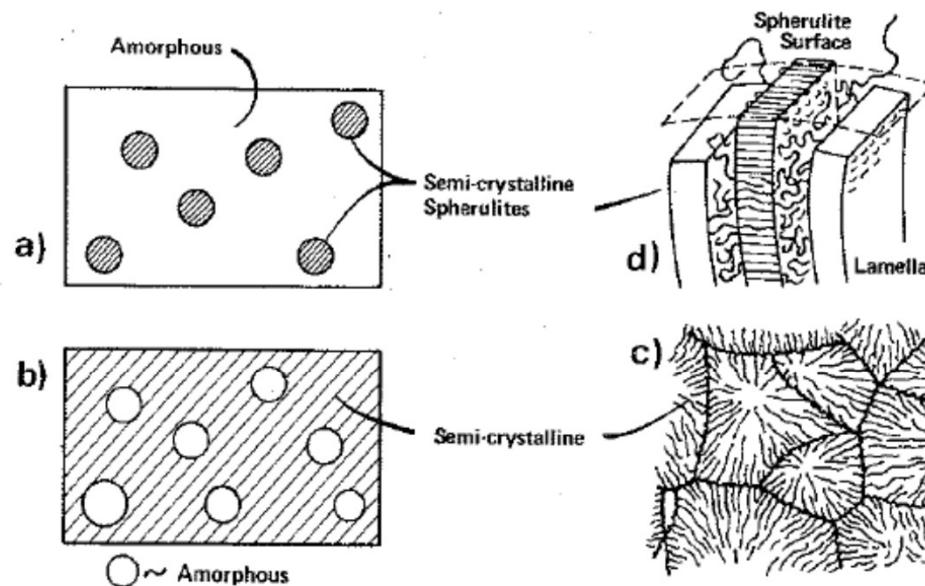


FIG. 9. Schematic morphology for the existence of a double glass transition. (a) isolated spherulites in continuous amorphous phase of $T_g = T_g(L)$; (b) rejected amorphous material of $T_g(L)$ at high x_c , actually appearing in grain boundaries as at (c); (d) Takayanagi model [34] showing interlamellar disorganized, or amorphous, material which may give rise to $T_g(U)$.

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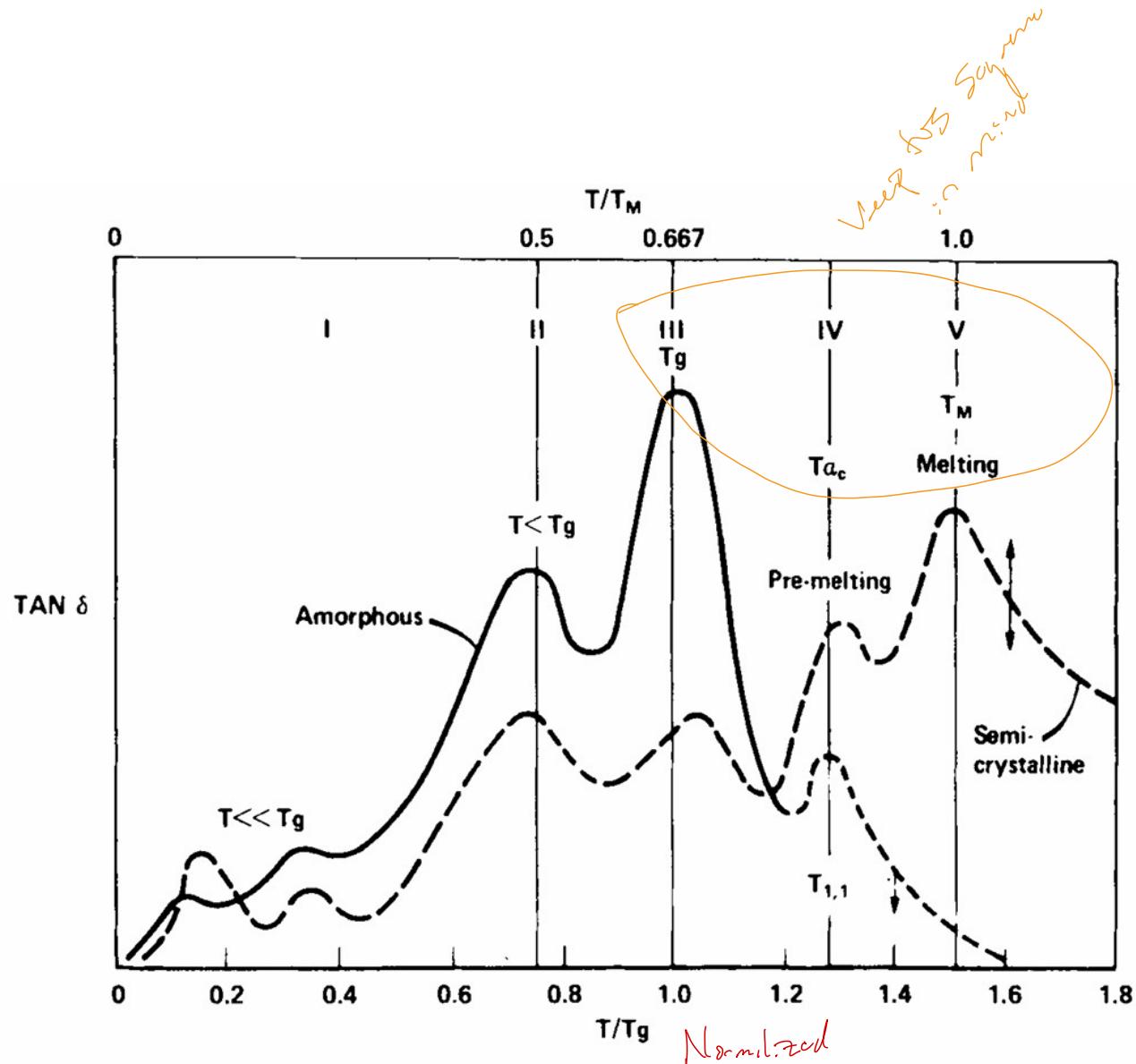
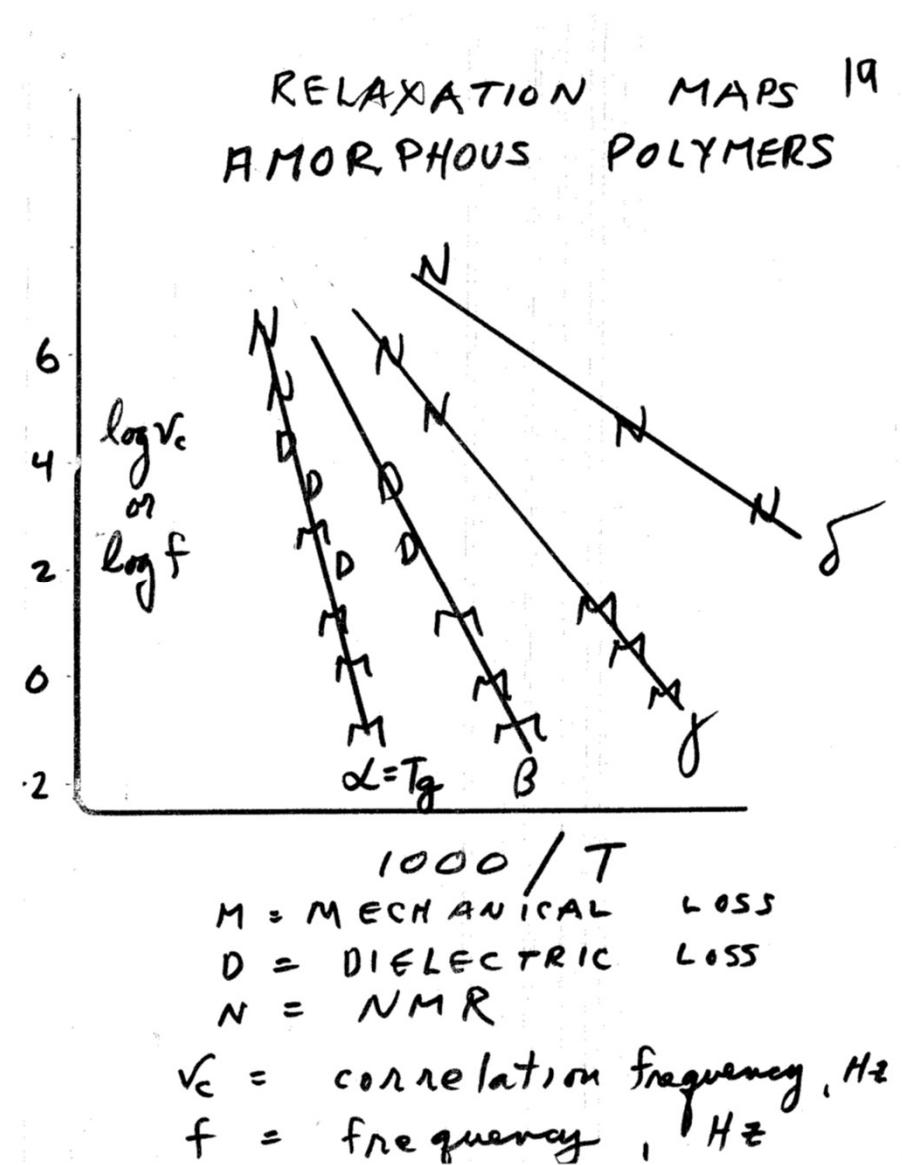


FIG. 6. Schematic "typical" mechanical relaxation spectra for atactic and bulk crystallized semicrystalline polymers. Roman numerals represent the several typical regions of activity. The designations associated with the several loss peaks are those used throughout this paper.

Image of Ray Boyer and Ray Boyer's class notes.



Plastics Hall of Fame Inductee



What is the Gamma Thermal Transition in Polyethylene

The gamma transition (T_g) in polyethylene refers to a low-temperature relaxation process involving localized movements of the CH₂ groups within the polymer chains, particularly in the amorphous and crystalline phases. It's essentially a type of molecular motion that occurs at relatively low temperatures, before the material transitions to a more flexible state.

- **Localized Movements:** The gamma transition involves small-scale movements of the CH₂ groups, which are the repeating units in the polyethylene chain. These movements can occur within both the amorphous (disordered) and crystalline (ordered) regions of the polymer.
- **Glass Transition and Relaxation:** The gamma transition region can also be considered part of the glass transition process, where the material transitions from a rigid, glassy state to a more rubbery, elastic state. In this context, the gamma transition reflects the onset of localized molecular motions that contribute to the overall change in material behavior.
- **Influence of Structure:** The structure of polyethylene, particularly the degree of crystallinity and the presence of defects, can influence the gamma transition. For example, differences in the structure of low-density and high-density polyethylene can affect the specific characteristics of the gamma transition in the crystalline phase.
- **Relevance to Mechanical Properties:** The gamma transition can impact the mechanical properties of polyethylene at lower temperatures. The ability of the CH₂ groups to undergo localized movements can influence the material's flexibility and toughness in the low-temperature range. In essence, the gamma transition in polyethylene represents a fundamental molecular motion that contributes to the material's overall behavior, especially at low temperatures, and can be viewed as a precursor to the larger-scale transitions that influence its mechanical properties.

What is the Beta Thermal Transition in Polyethylene

The beta (β) transition in polyethylene (PE) refers to a relaxation process that occurs in the temperature range of roughly -75°C to 0°C, and is associated with molecular motions in the amorphous regions of the polymer, particularly in the interlamellar regions between crystalline lamellae.

- **Nature of the Transition:** It's a solid-state transition, often considered a part of the broader glass transition phenomenon in amorphous polymers.
- **Molecular Mechanism:** The β -transition is believed to involve localized movements of chain segments, particularly in the amorphous regions between crystalline structures. These movements are related to the glass transition of polyethylene, where the polymer transitions from a rigid, glassy state to a more flexible, rubbery state.
- **Impact on Properties:** This transition can influence the mechanical and electrical properties of polyethylene at low temperatures. For example, the β -transition can affect the dielectric breakdown strength of LDPE (low-density polyethylene) at low temperatures.
- **Observed Effects:** The β -transition can be observed as a change in mechanical properties, such as an increase in loss modulus and tan delta in dynamic mechanical analysis (DMA) experiments, as well as changes in dielectric properties.
- **Controversy:** While the β -transition is well-established, the exact mechanism and the specific molecular motions involved are still a subject of some debate and research.

What is the Glass Transition in Polyethylene

The glass transition temperature (T_g) of polyethylene is the temperature at which the polymer changes from a rigid state to a rubbery state. The exact T_g depends on the type of polyethylene.

- **Low-density polyethylene (LDPE):** The T_g of LDPE is around -100°C . Below this temperature, LDPE is hard and rigid, and above it, it is rubbery.
- **High-density polyethylene (HDPE):** The T_g of HDPE is typically between -100°C and -130°C . Below this temperature, HDPE is hard and rigid.
- **Ultra-high molecular weight polyethylene (UHMWPE):** The T_g of UHMWPE is -80°C .

The T_g of a polymer is related to its thermal properties. The exact T_g depends on the structure of the polymer. For example, a small change in the structure of a polymer can result in a big change in its T_g .

The T_g of a polymer can be determined using differential scanning calorimetry (DSC) or dilatometry.

What is the Alpha Transition in Polyethylene

The alpha (α) thermal transition in polyethylene, also referred to as the α -relaxation or **the glass transition of the crystalline phase**, is a relaxation process associated with the segmental mobility of chain units within the crystalline regions of the polymer.

- **Segmental Mobility:** The α -transition involves the movement of relatively short segments of the polyethylene chains within the crystalline domains. This movement can be described as the rotation and/or translation of these chain segments along the chain axis.
- **Crystalline Regions:** While polyethylene is a semi-crystalline polymer, meaning it has both crystalline and amorphous regions, the α -transition specifically relates to the crystalline regions.
- **Importance:** This transition is significant because it influences the mechanical properties of polyethylene and plays a role in its behavior during processing and use.
- **Temperature Range:** The α -transition typically occurs at temperatures above the glass transition temperature (T_g) of the amorphous phase and below the melting point (T_m) of the crystalline phase. It's generally observed in the range of 303 to 393 K (30 to 120°C).
- **Factors Affecting α -transition:** The intensity and temperature of the α -transition can be affected by various factors like branching, copolymerization, and the presence of other chemical modifications in the polyethylene chain. In essence, the α -transition reflects the onset of chain mobility within the crystalline regions of polyethylene, influencing its mechanical and thermal properties.

GLASSY TRANSITIONS IN SEMICRYSTALLINE
POLYMERS

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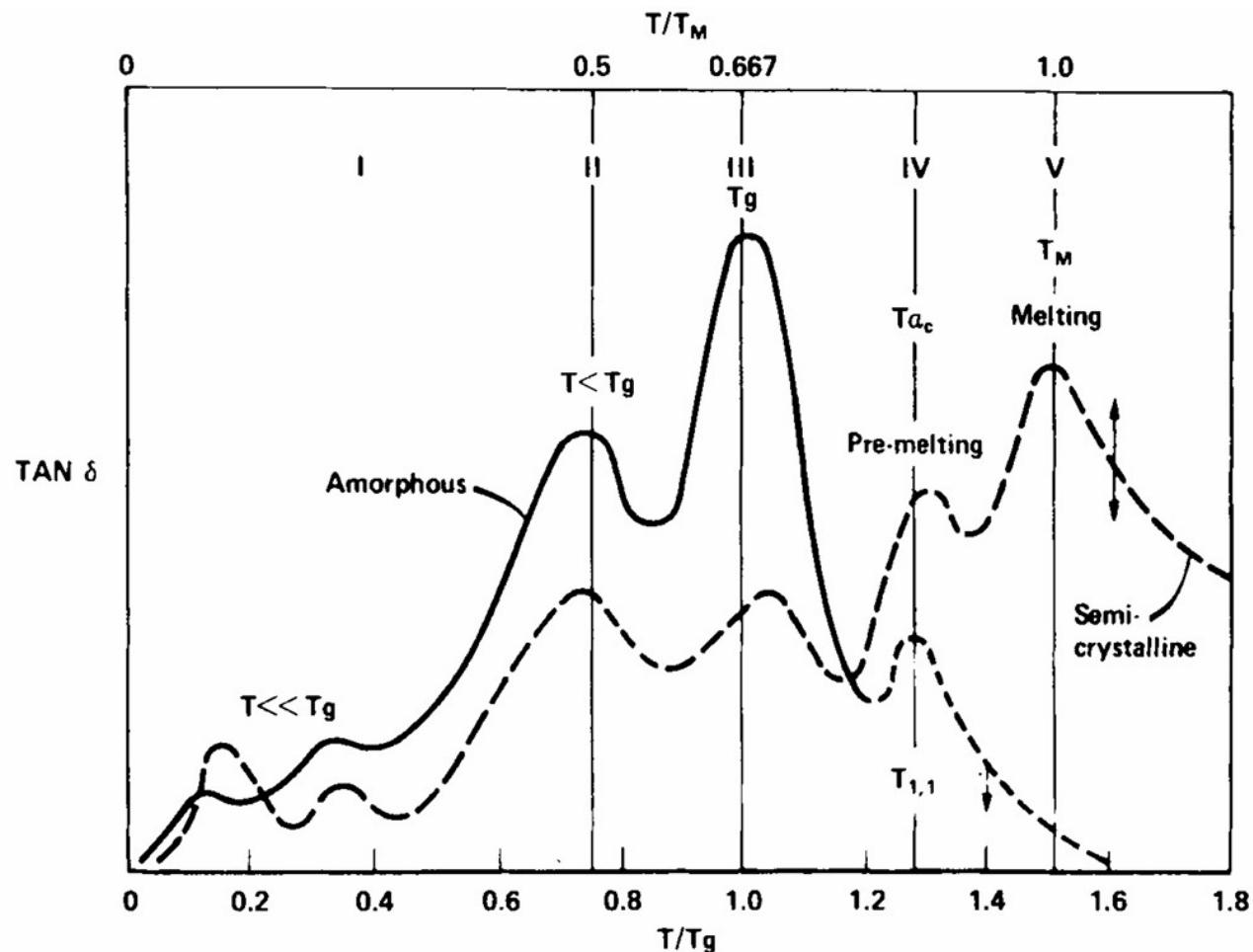


FIG. 6. Schematic "typical" mechanical relaxation spectra for atactic and bulk crystallized semicrystalline polymers. Roman numerals represent the several typical regions of activity. The designations associated with the several loss peaks are those used throughout this paper.

Amorphous linear polyethylene

POLYMER, 1979, Vol 20, July 903

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(Received 2 June 1978; revised 11 October 1978)

One of the results of the lack of amorphous polyethylene samples has been a long standing controversy over the location of the glass temperature (T_g) of PE. For details the reader is referred to several review articles by Boyer¹⁻⁴. The basic difficulty is that convincing experimental evidence, from several techniques, exists for T_g to be at any of three temperature ranges 145 ± 10 , 195 ± 10 and 240 ± 20 K. Boyer has attempted to resolve the problems by suggesting that 145K is the γ -transition where motions of segments 4–5 carbon atoms long begin, 195K is a lower T_g [$T_g(L)$] where motion of long chain segments unconstrained by crystallites occurs, and 240K is $T_g(U)$, where long segment motion occurs in chains held in tension or otherwise constrained by the lamellae.

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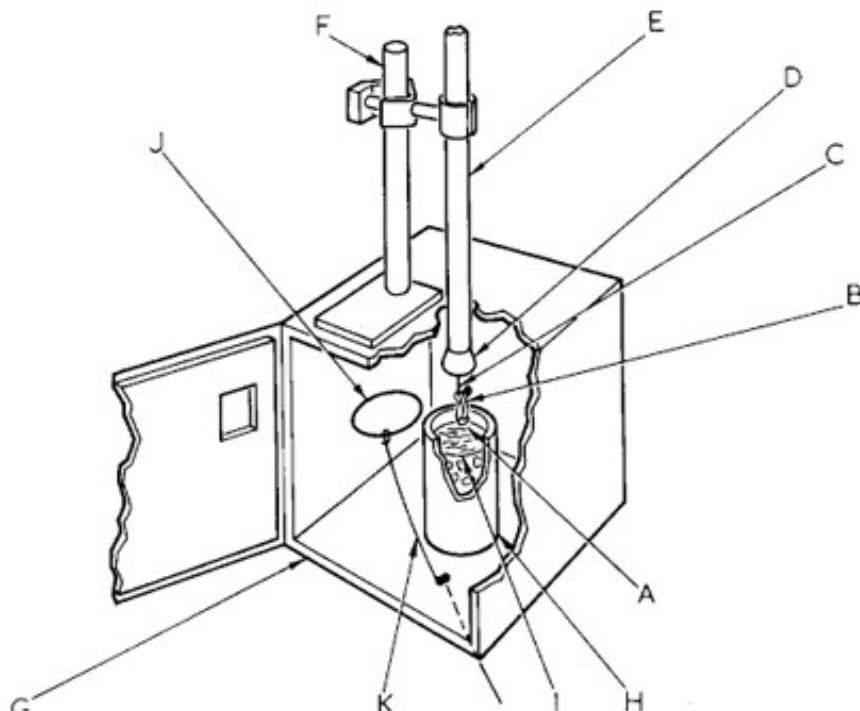


Figure 1 Nitrogen quench apparatus. A, Sample; B, clip; C, wire; D, cork; E, B-B gun; F, ring stand; G, furnace; H, dewar; I, quenchant; J, dewar cover; and K, cover wire

Nitrogen quench method

A schematic diagram of the quench apparatus is shown in *Figure 1*. The sample on its grid (A) was suspended vertically by a small steel alligator clip (B) attached to a 3–4 in. copper wire (C), the end of which was inserted into the large end of a cork (D). The cork was properly sized to fit into the end of the barrel of a Daisy Model 1105-BB gun (E) which had been sawed off 1.5 cm above the maximum extension of the plunger. The gun was clamped vertically to a ringstand (F) on the top of the furnace (G) in such a manner that the barrel extended through a hole in the top of the furnace. The height of the gun along the ringstand determined how far the sample hung above the tall Dewar (H) contained the quenchant. About one inch from the sample to the top of the Dewar seemed to be a satisfactory distance.

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The first step of the quench procedure was to insert the cork bearing the wire and sample into the cocked BB gun so that the sample would be propelled straight down onto the quenchant. Alignment was critical for a fast quench. The sample was allowed to melt at 180°C for 5–10 min while the quenchant was prepared. The Dewar, filled with the nitrogen mixture to within 1 cm of the top, was placed quickly in the furnace directly under the sample. The cover was then set in place and the furnace was again closed. When the temperature in the furnace reached about 155K, the cover on the Dewar was removed. Care was taken to minimize vibrations of the gun that might keep the cork from going straight to the bottom of the Dewar. The cork permitted easy removal of the sample. The sample was kept inside a small beaker of liquid nitrogen during subsequent handling to keep it from warming.

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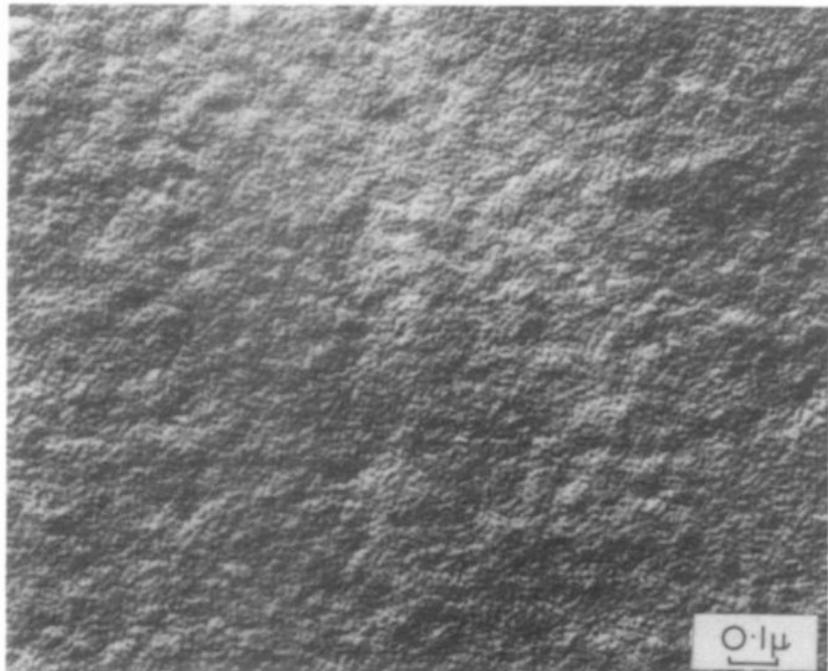


Figure 8 Nitrogen-quenched LPE film that gave predominantly amorphous diffraction when cold. Sample was kept cold before and during insertion and observation in the EM. Upon warming it was entirely crystalline. Pt/C shadowed after warming

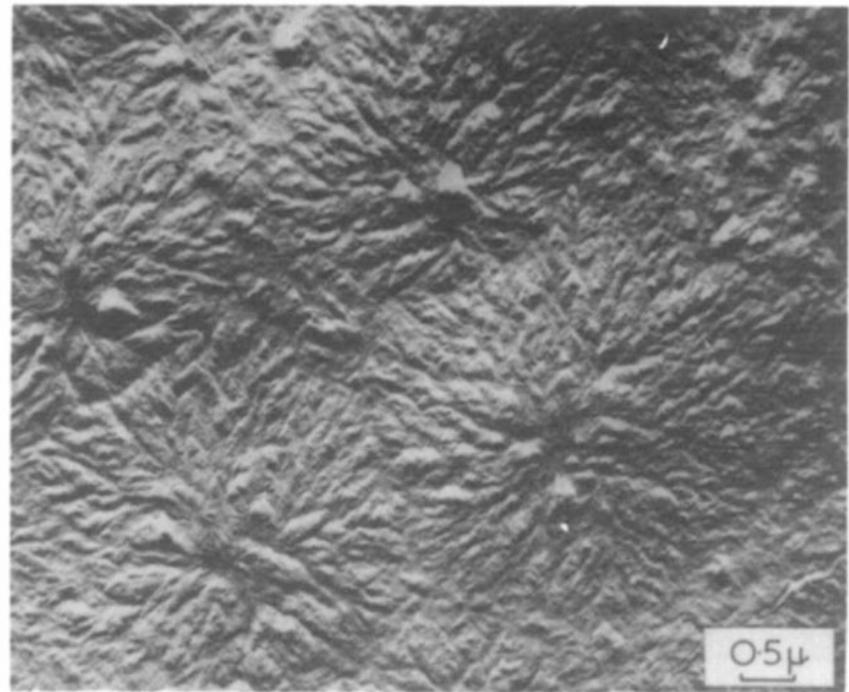


Figure 7 Spherulites in badly nitrogen-quenched LPE film. Sample was kept cold before and during Pt/C shadowing

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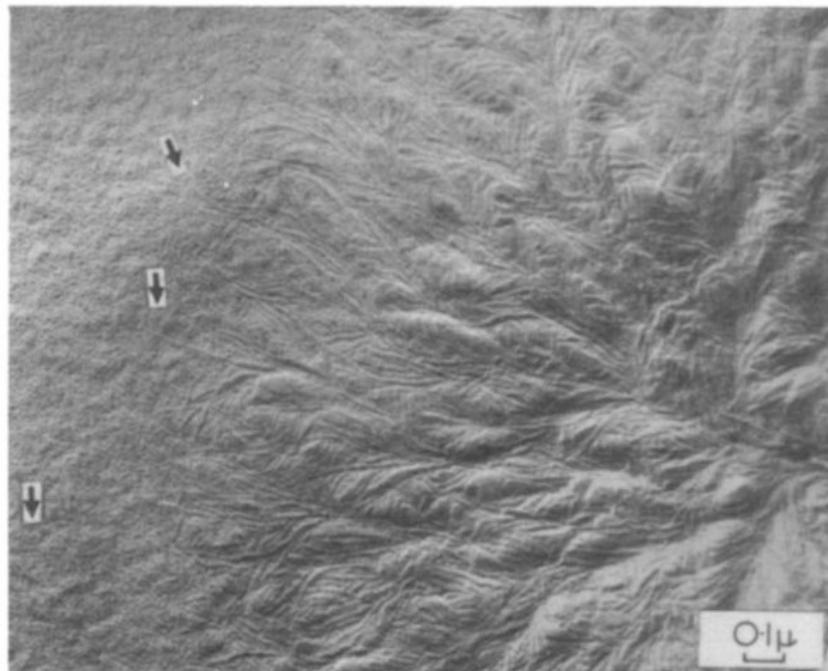


Figure 9 Boundary between crystalline and presumably amorphous areas of nitrogen-quenched LPE film. Arrows mark lamellae in which the nodules do not seem to have coalesced completely. Pt/C shadowed after warming

Amorphous linear polyethylene

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Conclusion

160K and 180K. Above 180K the amorphous portions of the spectrum are gradually converted to crystalline bands, suggesting that the true T_g lies around 180K.

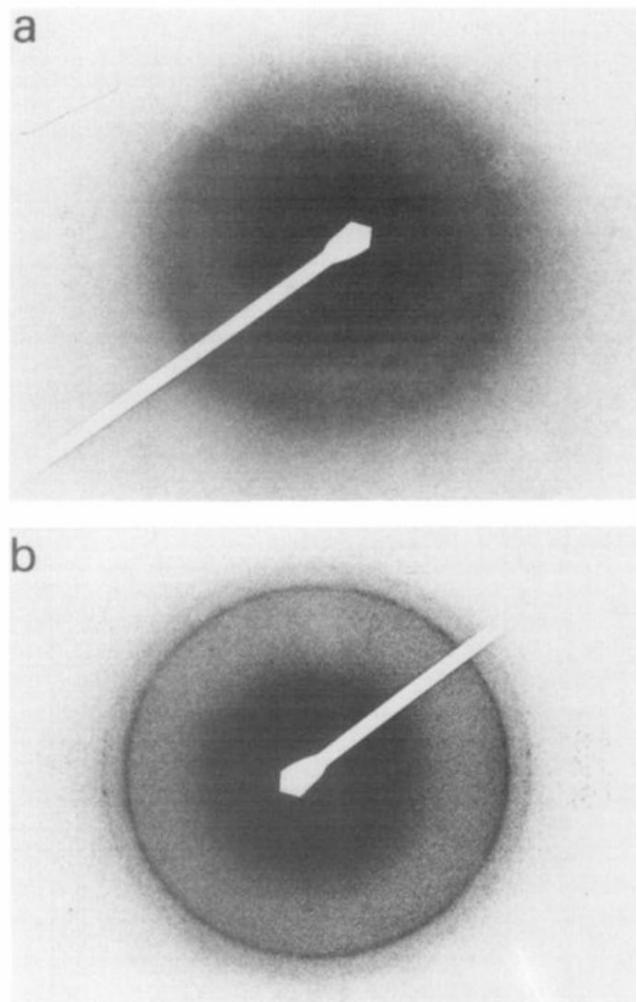


Figure 16 (a) Electron diffraction pattern of nitrogen-quenched LPE film kept cold before and during insertion and observation in EM. Carbon substrate. (b) Diffraction pattern from same film after warming to room temperature

Critical Properties for the Differentiation of the Polyethylene Types

Density

Crystalline Region

Perfect 1.00 g/cm³

Unit Cell Calculation (orthorhombic) 0.996

Single Crystal Determination 0.972

Amorphous Region 0.850 – 0.855

Transition Temperatures

Glass Transition Temperature -78 C (195 K)

Melt Transition Temperature (density dependent) 130-140 C

The Most Common Classification of Polyethylene is by Density

Table 1. Classification of polyethylenes by density

<i>Resin family</i>	<i>Lower density limit g/cc</i>	<i>Higher density limit g/cc</i>
High Density Polyethylene (HDPE)	0.941	0.975
Medium Density Polyethylene (MDP)	0.928	0.941
Linear Low Density Polyethylene(LLDPE/LDPE)	0.915	0.928
Very Low Density Polyethylene (VLDPE)	0.900	0.915
Elastomers/Plastomers	0.865	0.900

These Variations of Polyethylene Lead to a Diversity of Products

Linear Versions:

High density polyethylene (HDPE)

Ultra-high molecular weight polyethylene (UHMWPE)

Branched Versions:

Low-density polyethylene (LDPE)

Linear low density polyethylene (LLDE)

Medium-density polyethylene (MDPE)

Very-low-density polyethylene (VLDPE)

High-molecular-weight polyethylene (HMWPE)

Ultra-low-molecular-weight polyethylene (ULMWPE)

Chlorinated polyethylene (CPE)

Bimodal and Trimodal Polyethylene

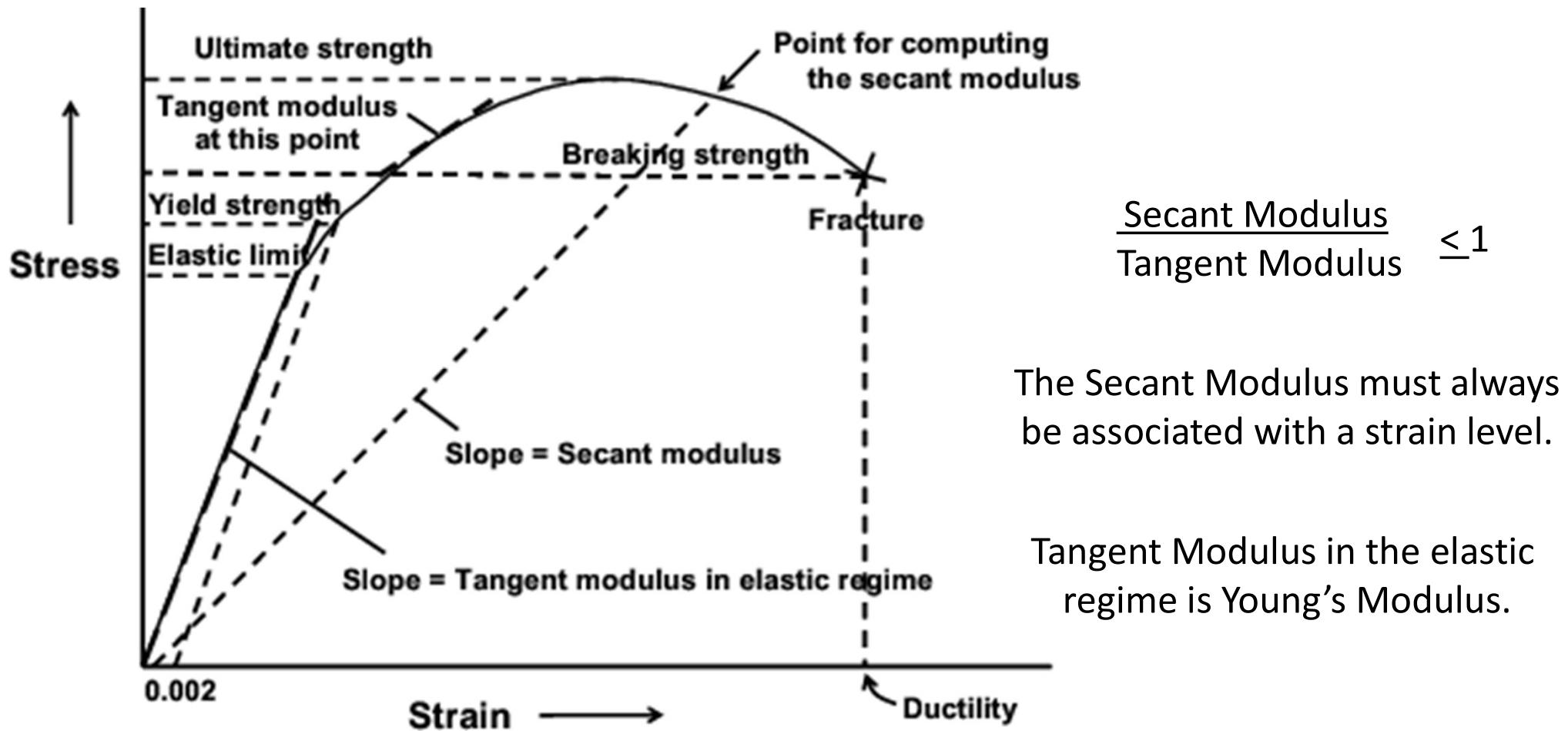
Cross-linked polyethylene (PEX): four forms (PEX-a, PEX-b . . etc)

Simplest of Monomer Structures Can Lead to a Large Diversity of Polymer Structures.

Three fundamental features of polyethylene leading to the diversity of structures and in turn performance are:

- a. Short chain and long chain branching.
- b. Co-monomer content and distribution.
- c. Molecular weight and molecular weight distribution.

Tensile Properties of Plastics is a Fingerprint of the Mechanical Performance



Molecular weight Dependence on Polyethylene Properties

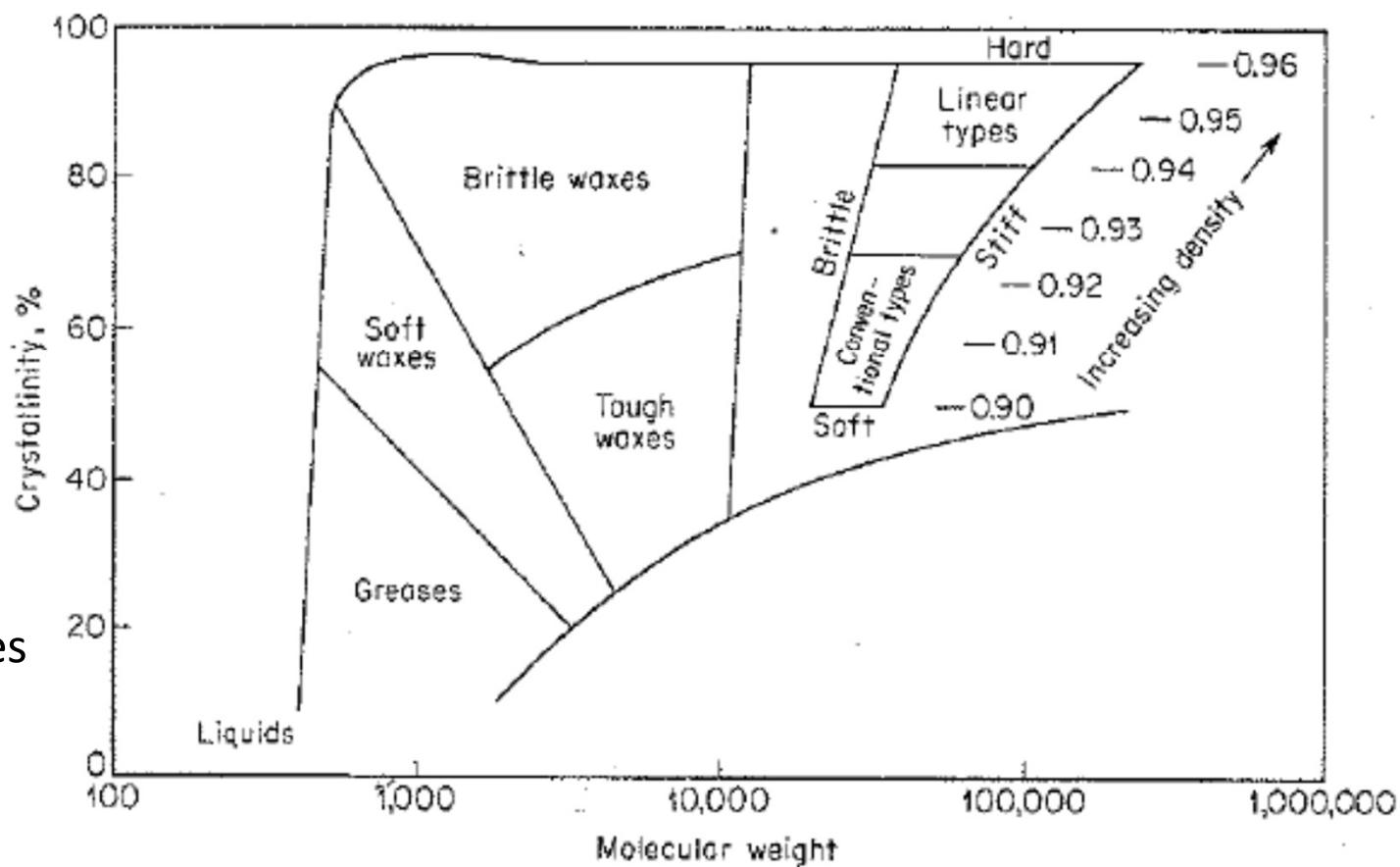


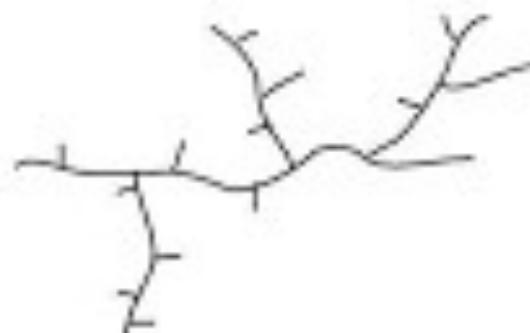
FIGURE 13-1

Relationships between crystallinity, molecular weight, and mechanical properties of polyethylene [3]. (After Kratz and Lyle, *Encyclopedia of Chemical Technology*, First Suppl., Interscience, 1957.)

The Variance of Most Polyethylene Products is Based on Branching



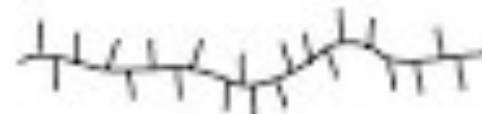
High-Density Polyethylene (HDPE)
 $X_c \sim 55\text{-}77\%$ $T_m \sim 125\text{-}132^\circ\text{C}$



Low-Density Polyethylene (LDPE)
 $X_c \sim 30\text{-}54\%$ $T_m \sim 98\text{-}115^\circ\text{C}$



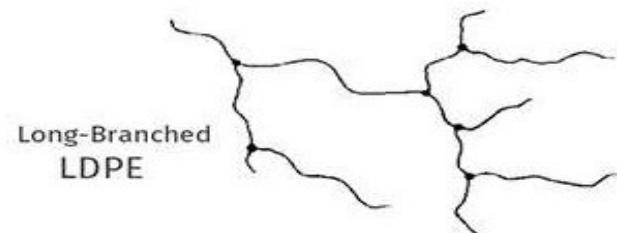
Linear Low-Density Polyethylene (LLDPE)
Branching density ~ 25-100 C atoms
 $X_c \sim 22\text{-}55\%$ $T_m \sim 100\text{-}125^\circ\text{C}$



Very Low-Density Polyethylene (VLDPE)
Branching density ~ 7-25 C atoms
 $X_c \sim 0\text{-}22\%$ $T_m \sim 60\text{-}100^\circ\text{C}$

Low Density Polyethylene (LDPE)

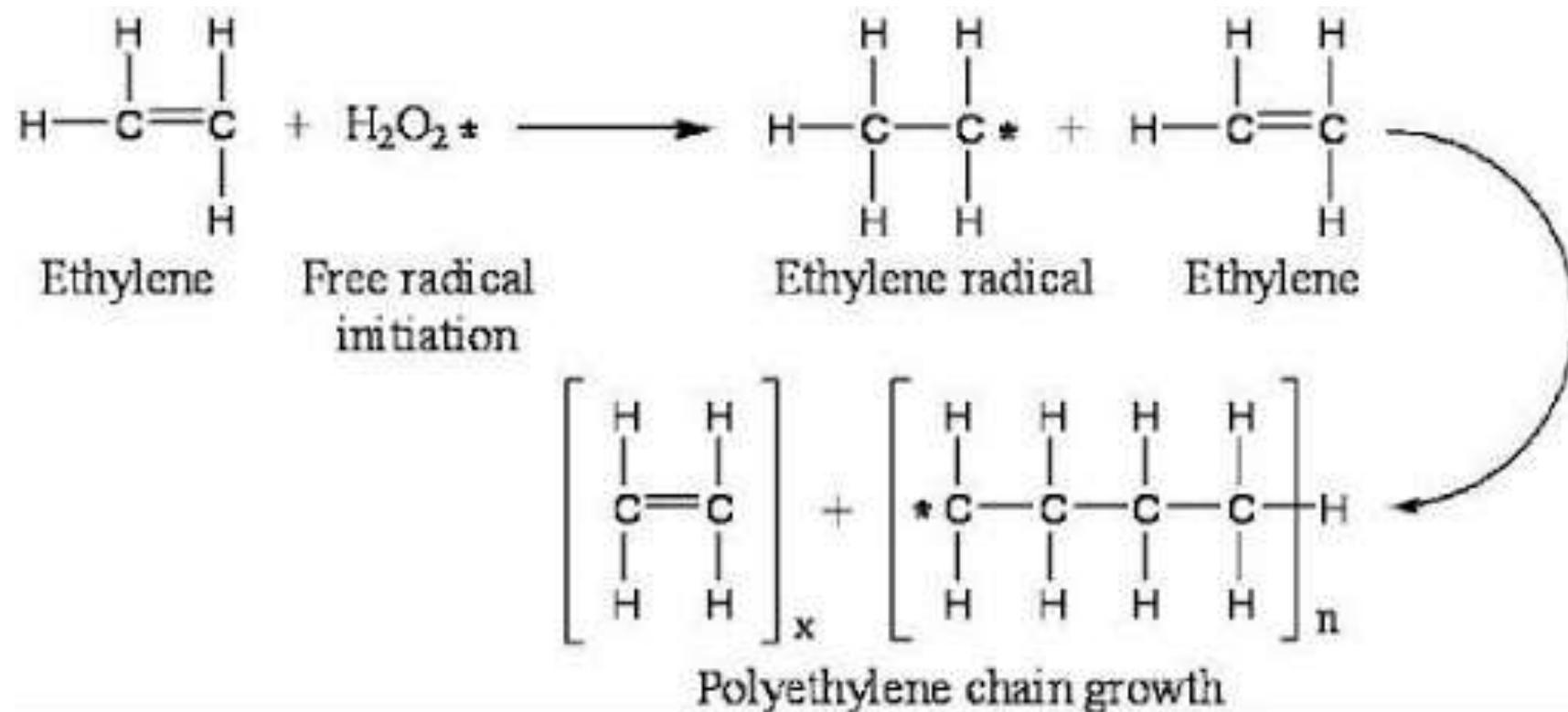
- LDPE was the first polyethylene commercially produced.
- It is the only one made utilizing free radical chemistry under high temperatures and pressures.
- Its unique structure contains long chain branching which makes it highly desirable in the manufacture of thin films either by itself or blends with other types of polyethylene.
- Its long chain branching is a consequence of the high pressure process where intermolecular hydrogen abstraction by a growing chain end from another polyethylene is the source of this highly desirable properties especially in melt processing.



Low Density Polyethylene (LDPE)

- The presence of long chain branches has a significant impact on the rheology of low density polyethylene.
- The presence of long chain branches increases the shear thinning of the polymer, meaning at high shear rates the polymer has lower viscosity than expected while at low shear rates the polymer has higher viscosity than expected.
- The low viscosity at high shear rates also helps to reduce the energy required to process the resin.

Free Radical Polymerization of LDPE



Process Schematic for Producing Low Density Polyethylene

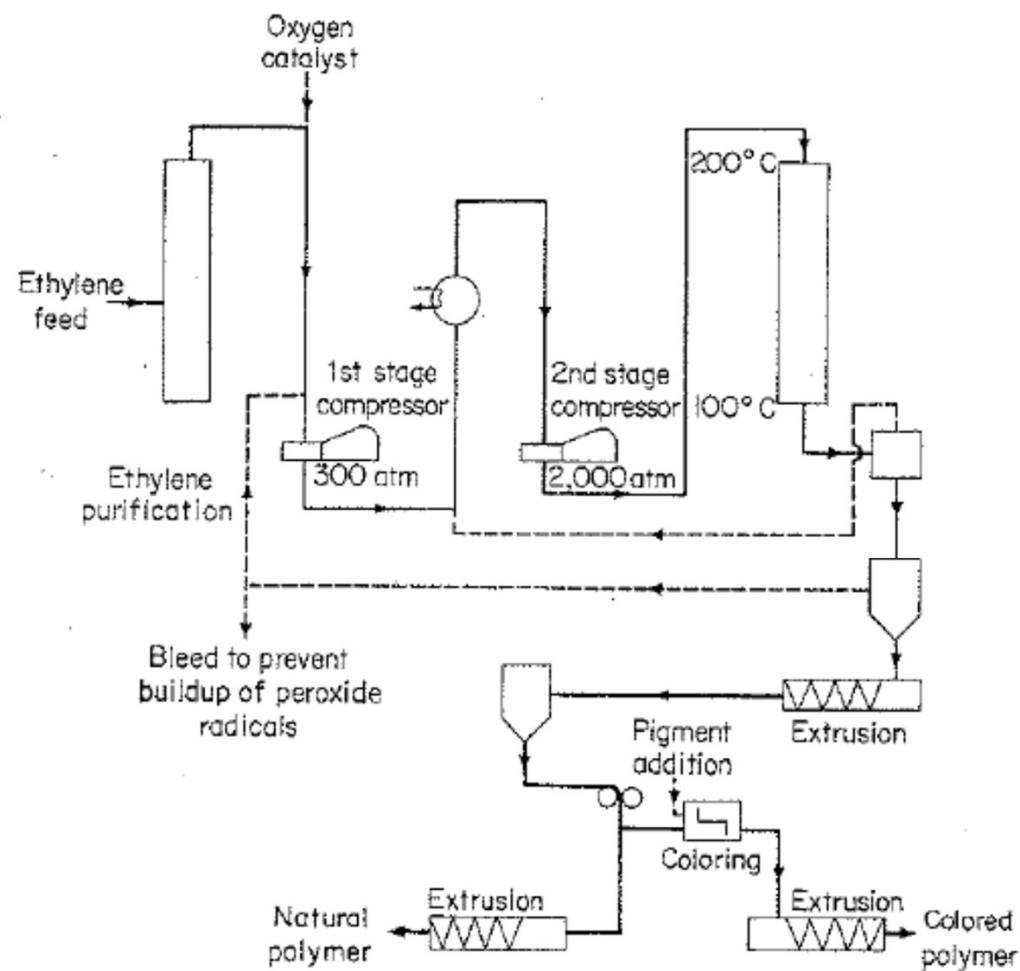


FIGURE 13-2
Simplified flow scheme for the high-pressure polymerization of ethylene [4].

Properties of Low Density Polyethylene

- LDPE Melting Point: 105 – 115 C
- Density of LDPE: 0.910 – 0.940 g/cm³
- Chemical Resistance of LDPE
 - Good resistance to alcohols, dilute alkalis and acids
 - Limited resistance to aliphatic and aromatic hydrocarbons, mineral oils, oxidizing agents and halogenated hydrocarbons
- Operating temperature up to 80 C continuously and 95 C for short periods
- Low cost polymer with good processability
- High impact strength at low temperatures, good weatherability
- Excellent electrical insulating properties
- Very low water absorption.
- FDA compliant
- Transparent in thin film form

Disadvantages of Low Density Polyethylene

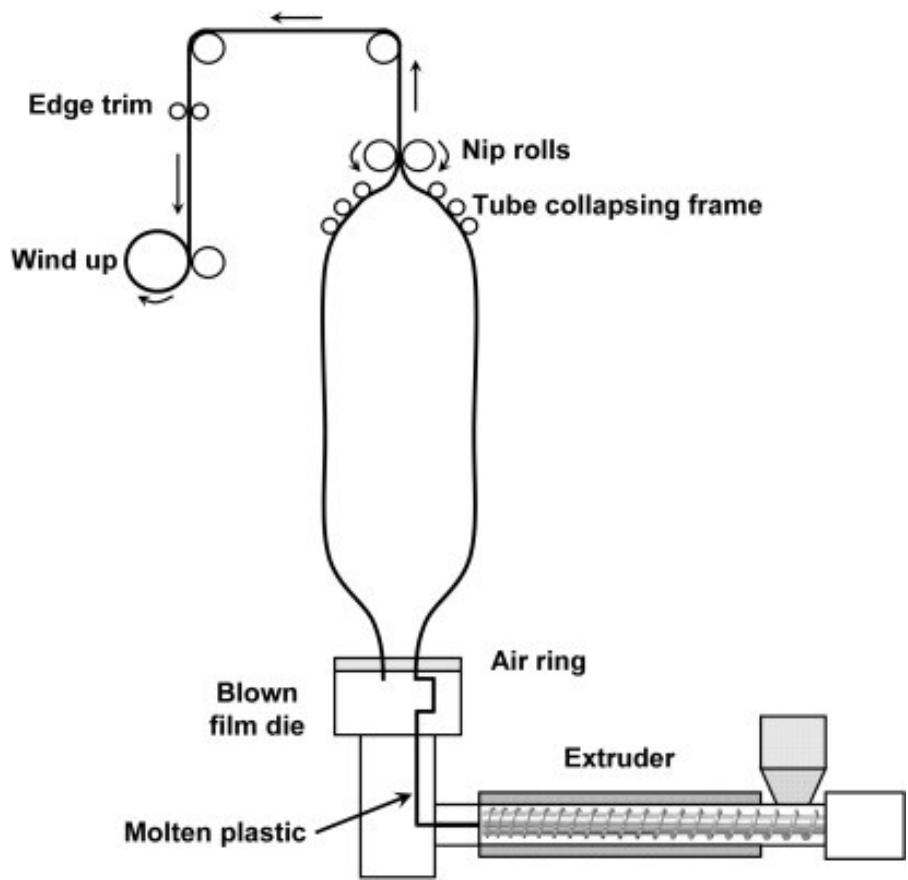
- Susceptible to stress cracking (ESC – Environmental Stress Cracking)
- Low strength, stiffness and maximum service temperature
- High gas permeability, particularly carbon dioxide
- Poor UV resistance
- High flammability
- Impossible to apply high frequency welding and joining

Applications for Low Density Polyethylene

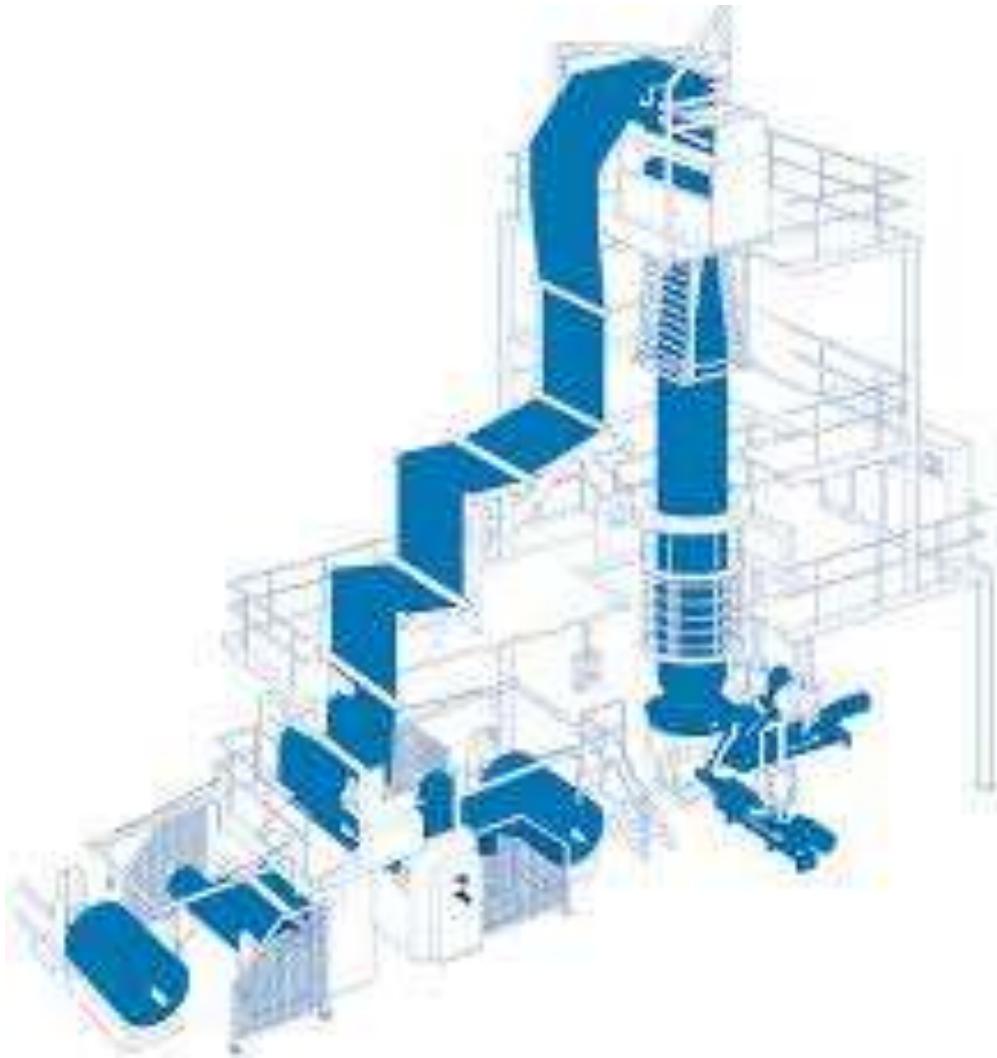
The most popular application of LDPE is the production of plastic bags. Due to the Low cost and flexibility, LDPE is used in the packaging industry for pharmaceutical And squeeze bottles, caps and closures, tamper evident, liners, trash bags, Films for food packaging (frozen, dry goods, etc.) and laminations.

Low Density Polyethylene is also used to manufacture water pipes and hoses For the pipe and fitting industry due to its flexibility and low water absorption.

One End-Use for LDPE is PE Bags by the Blown Film Process



The Blown Film Process for Low Density Polyethylene



Other End-Use Products Made from LDPE

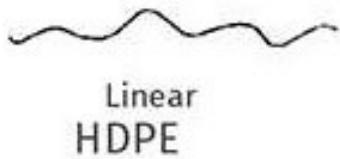


LDPE



High Density Polyethylene (HDPE)

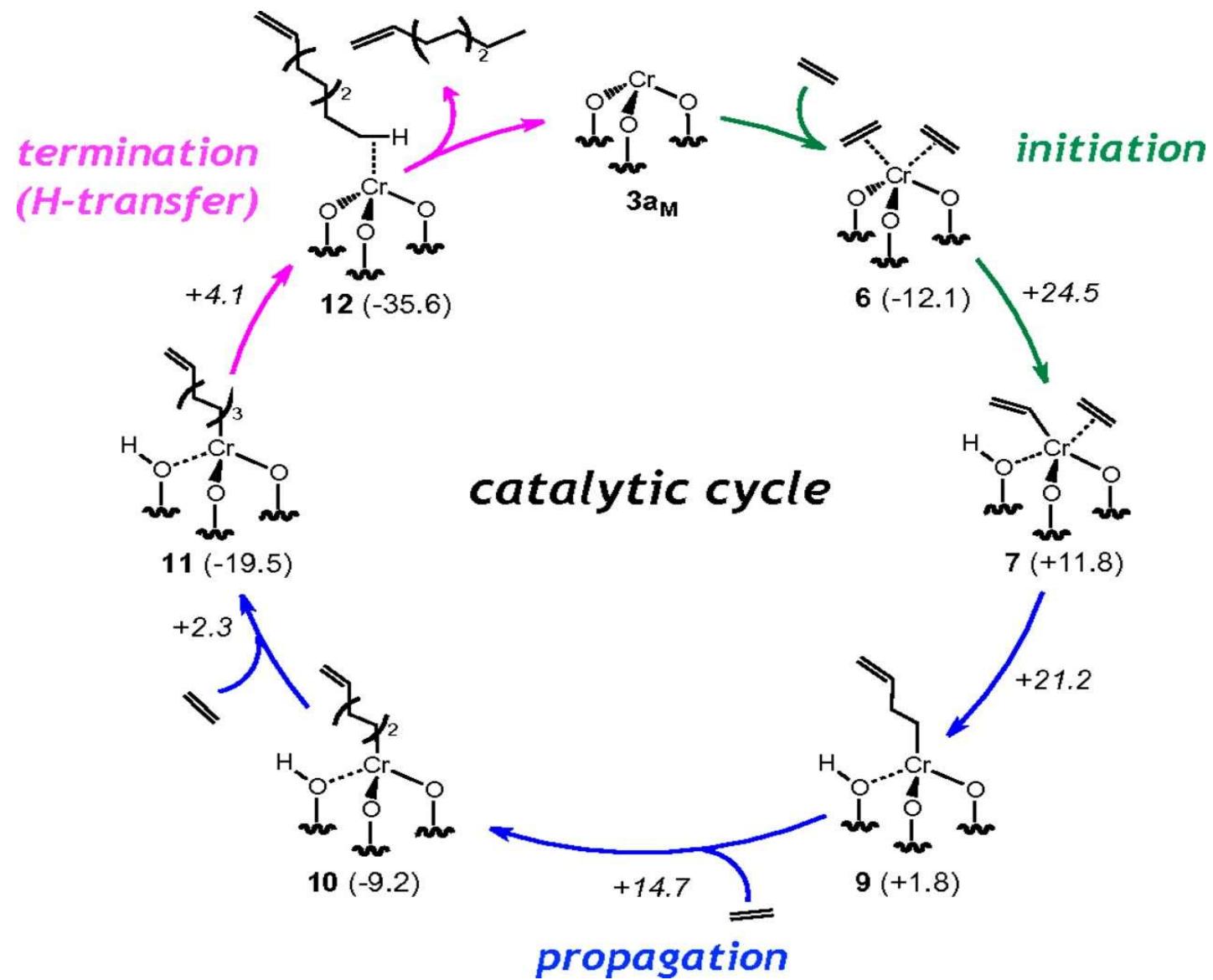
Unlike low density polyethylene (LDPE) which utilizes free radical chemistry, high density polyethylene (HDPE) is produced through coordination chemistry catalysis.



There are three basis coordination chemistry catalyst used to produce HDPE:

1. Chromium Catalyst for Slurry and Gas Phase Process – developed in the early 1950's by Robert Banks and J. P. Hagen at Phillips Petroleum. Initially used chromium trioxide. Required lower pressures (< 1000 psi) and lower temperatures (80 – 110 C).

Phillips Petroleum
Chromium Catalysis
for the Polymerization
Of Polyethylene



High Density Polyethylene (HDPE)

There are three basis coordination chemistry catalyst used to produce HDPE:

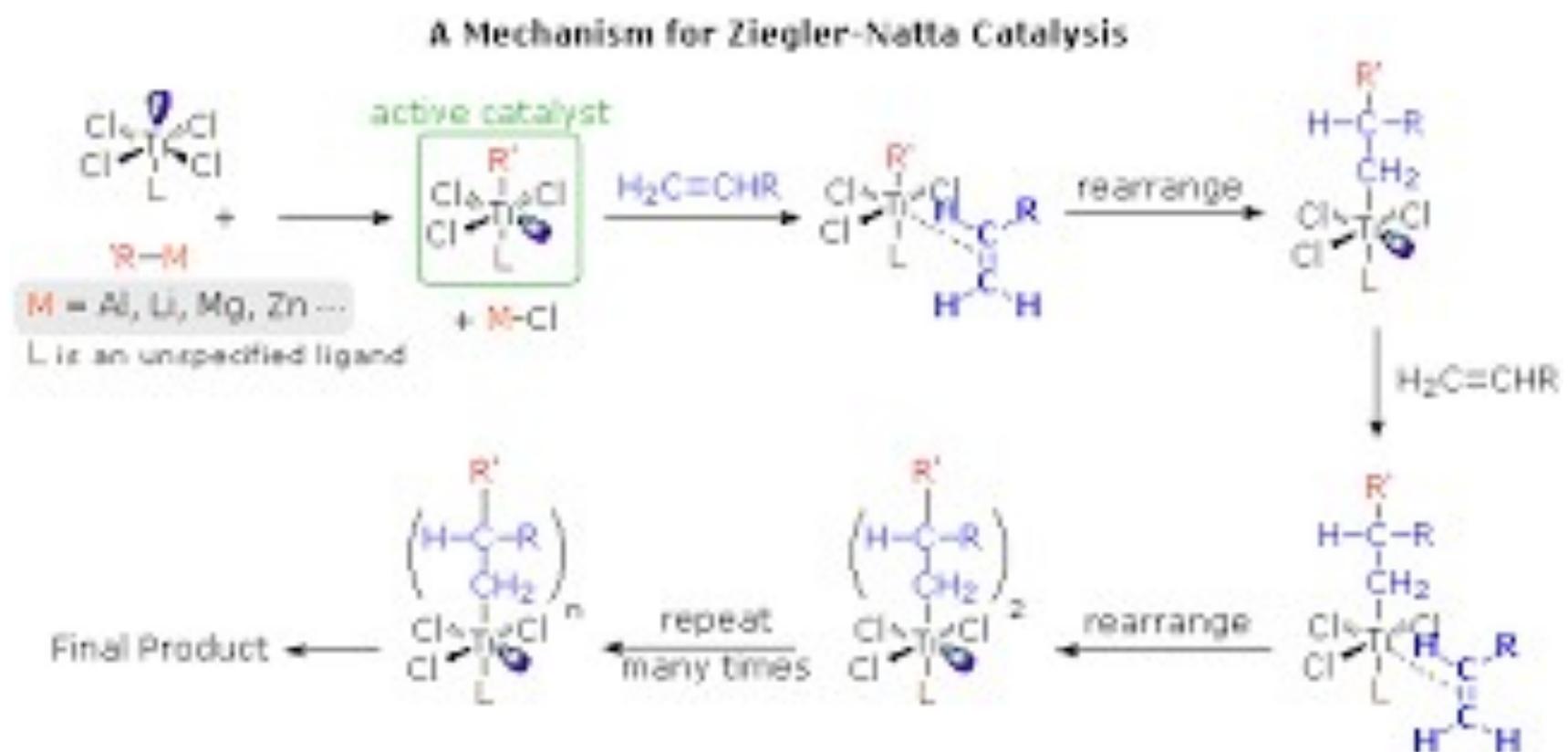
2. Ziegler – Natta Polymerization and the Gas Phase Process

This process was initially developed by Karl Ziegler at the Max Plank Institute in Mulheim, Germany and later refined by Giulio Natta , at the Institute of Industrial Chemistry In Milan, Italy. Natta used the titanium tetrachloride discovered by Ziegler and enhanced it with an aluminum alkyl.

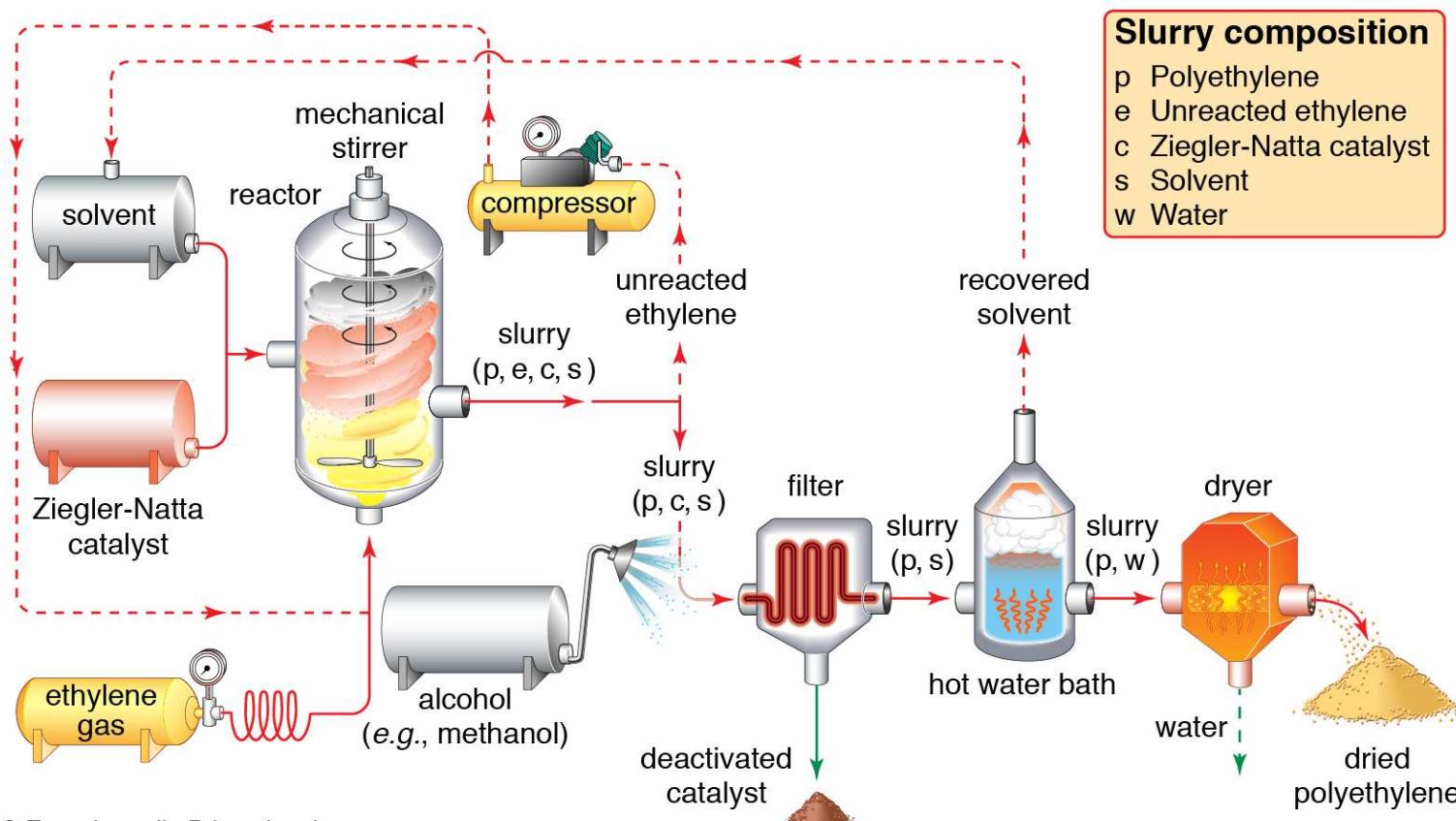
Initial Z-N catalysts were not supported and the active site activity would become limited.

In 1970 supported Z-N catalysts were developed to enhance the catalyst activity: $Mg Cl_2$

Ziegler – Natta Polymerization Mechanism



Ziegler-Natta Polymerization Process for HDPE

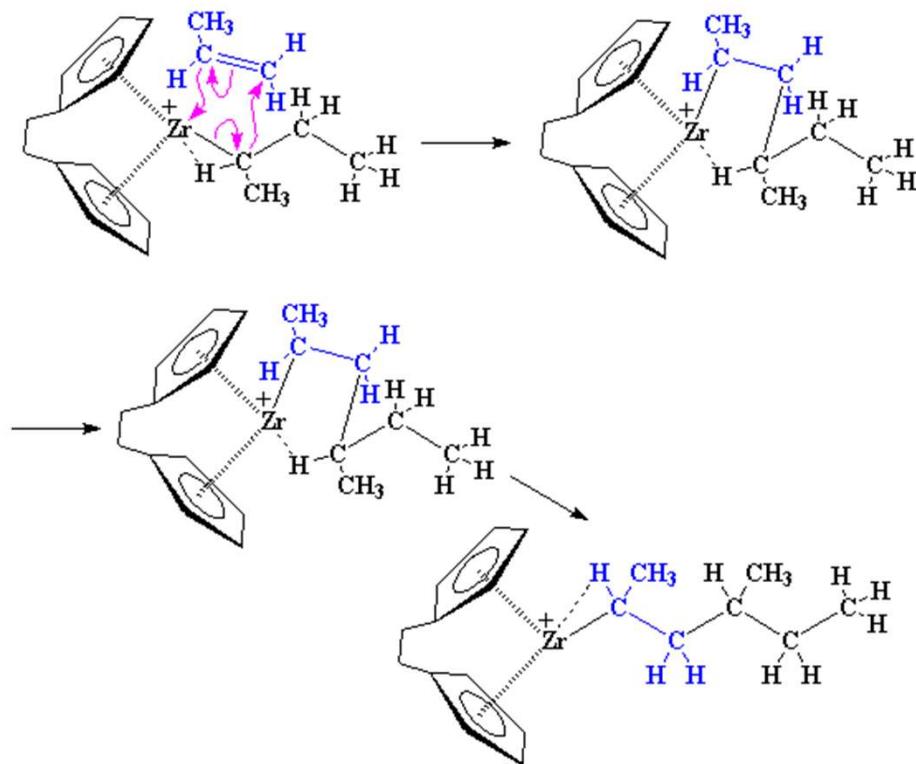


High Density Polyethylene (HDPE)

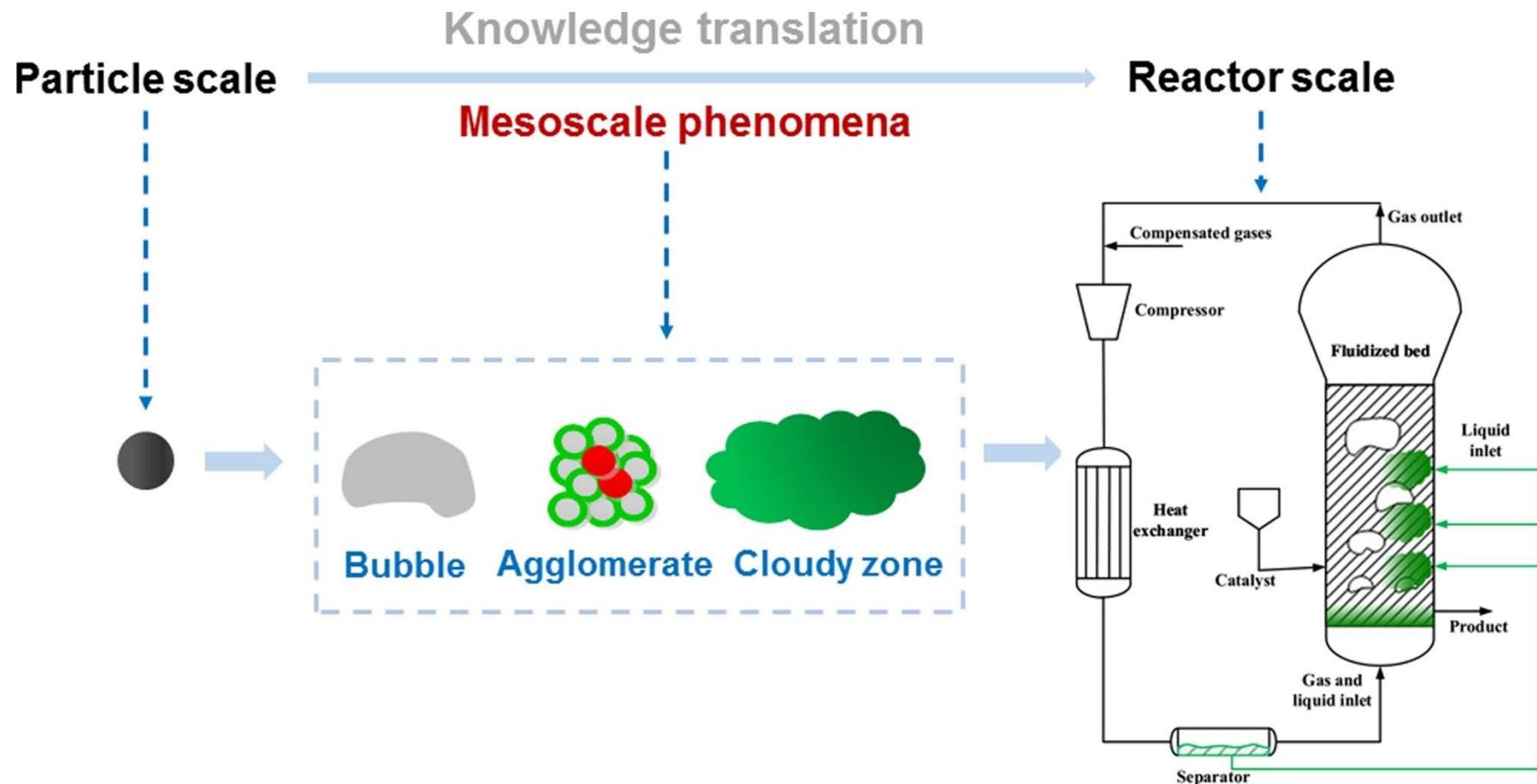
There are three basis coordination chemistry catalyst used to produce HDPE:

3. Metallocene Catalysts - The newest type of PE catalysts having much higher control on the molecular parameters. First discovered in 1976 by Walter Kaminsky and Hansjorg Sinn in Germany. The process can be either slurry or gas phase. This catalyst system has only one active center which results in having the copolymer molecular composition always the same. Very high yields are produced by this catalysis system: millions of grams of polymer per gram of catalyst.

Metallocene Polymerization Mechanism



Metallocene Polymerization Process for HDPE



High Density Polyethylene (HDPE)



High Density Polyethylene

The chemical structure of high density polyethylene (HDPE) lends itself to greater toughness – roughly twice the tear and puncture strength and better chemical resistance than low density polyethylene (LDPE) and linear low density polyethylene (LLDPE). On the downside, HDPE film is less flexible and less clear than its LDPE and LLDPE cousins.

courtesy of LADDAWN

Properties of High Density Polyethylene

- HDPE Melting Point: 120 – 140 C
- Density of LDPE: 0.93 – 0.97 g/cm³
- Chemical Resistance of LDPE
 - Excellent resistance to most solvents
 - Very good resistance to alcohols, dilute alkalis and acids
 - Moderate resistance to oils and greases
 - Poor resistance to aliphatic and aromatic hydrocarbons, mineral oils, oxidizing agents and halogenated hydrocarbons
- Operating temperature from – 50 to 60 C
- Relatively stiff material with useful temperature capabilities
- Higher tensile strength compared to other forms of polyethylene
- Good low temperature resistance
- Excellent electrical insulating properties
- Very low water absorption.
- FDA compliant

Disadvantages of High Density Polyethylene

- Susceptible to stress cracking (ESC – Environmental Stress Cracking)
- Low strength, stiffness
- High gas permeability, particularly carbon dioxide
- Poor UV resistance; can be modified with carbon black
- High flammability
- Impossible to apply high frequency welding and joining

Applications for High Density Polyethylene

1. Packaging Applications – High density polyethylene is used in several packaging applications including crates, trays, bottles for milk and fruit juices, drums, and industrial bulk containers.
2. Consumer goods – Low cost and easy processability make HDPE a material of choice in several household/ consumer goods like garbage containers, housewares, ice boxes and toys.
3. Fibers and Textiles – Due to its high tensile strength, HDPE is widely used in ropes, fishing and sport nets, nets for agricultural use, and industrial and decorative fabrics.

Other applications include pipe and fittings (gas, water, sewage, drainage), wire and cable coating, steel pipe coating and automobile fuel tanks.

Performance Comparison LDPE and HDPE

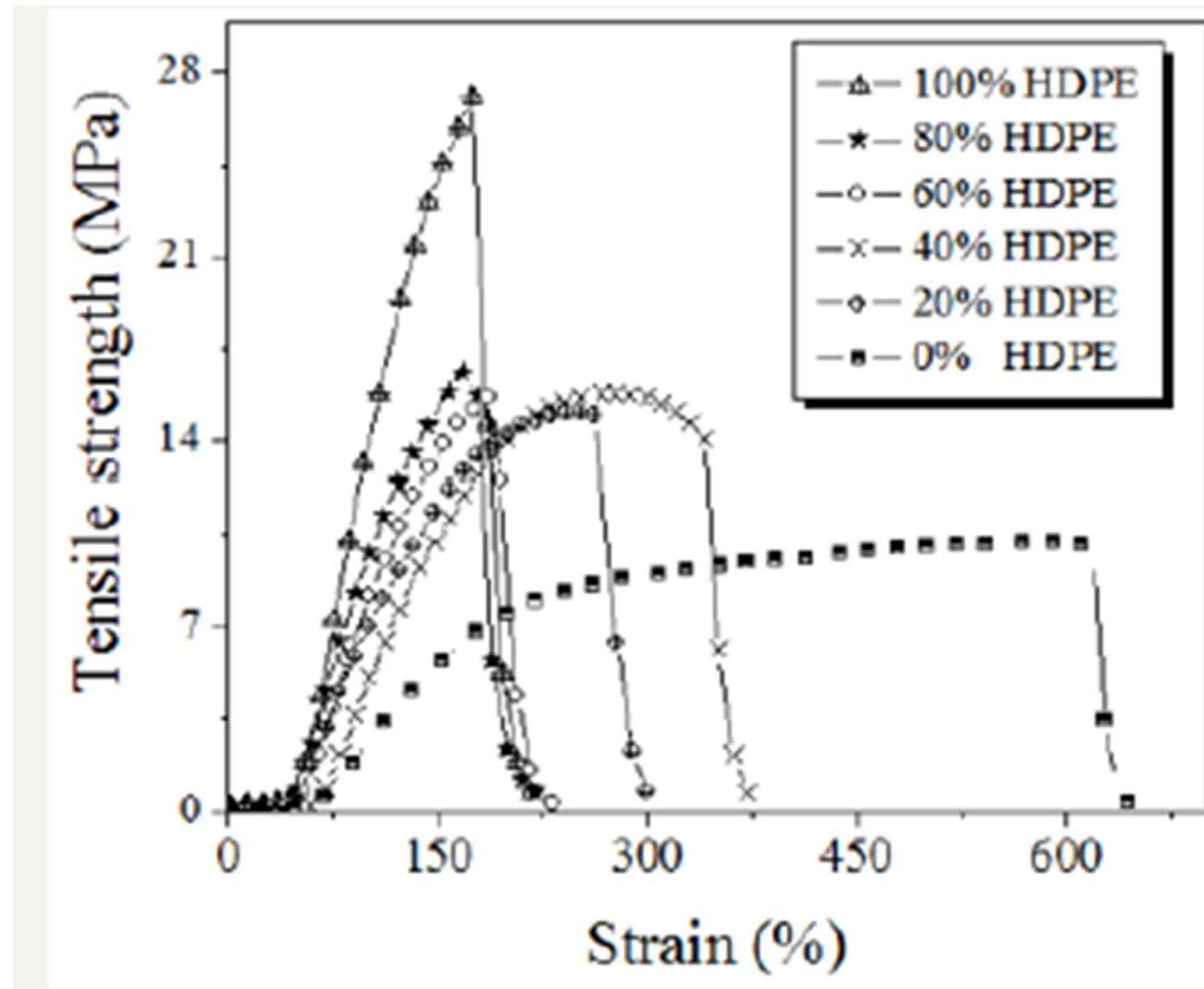
Material	Density (kg/m ³)	Tensile modulus (GN/m ²)	Shear modulus (GN/m ²)	Poisson's ratio
Polyethylene- High Density (HDPE)	955	1.05	0.39	0.34
Polyethylene- Low Density (LDPE)	920	0.32	0.11	0.45

Performance Comparison LDPE and HDPE

Properties	LLDPE*	LDPE*	HDPE*	HDPE-pc
Density (g/cm ³)	0.910 - 0.925	0.915 - 0.935	0.941 - 0.967	-
Melting (0C)	121 - 125	106 - 112	130 - 133	130
Stress (MPa)	14 - 21	7 - 17	18	20
Elongation (%)	200 - 1200	100 - 700	20 - 100	12
Impact resistance (J/m)	-	0.67 - 21	27 - 160	42
Elastic modulus (MPa)	100 - 200	102 - 240	960 - 1000	453

*According to references 17 and 18.

Tensile Performance Change when Modifying HDPE with LDPE



Lesson 10: Polyolefin – PE 2

Questions?



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“Having plans sounds like a good idea until you have to put on clothes and leave the house.”