POLYMERS 101

PDA TRAINING COURSE
EXTRACTABLES – LEACHABLES
BASEL
27 -28 FEBRUARY 2020

Dr. Piet Christiaens

OVERVIEW

1. What is a polymer?
2. Classification of polymers
 - natural vs synthetic polymers
 - thermoplast vs thermoset polymers
 - homo-, co-, cross-linked and grafted polymers
 - polymerisation mechanism
3. Properties of polymers
 - morphology
 - glass transition temperature
4. Composition of commercial polymers
 - additives
 - residues
 - catalysts
 - oligomers
 - degradation compounds
5. Processing of polymers

1. WHAT IS A POLYMER?

A **polymer** is a chemical compound or mixture of compounds consisting of repeating structural units created through a process of polymerization

Greek words:

πολύς (polus, meaning "many, much")

μέρος (meros, meaning "parts")

Refers to a molecule whose structure is composed of **multiple repeating units**

As a consequence:

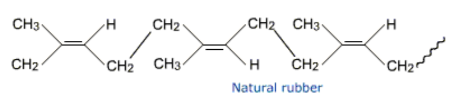
- a characteristic of high relative molecular mass and
- associated properties

OVERVIEW

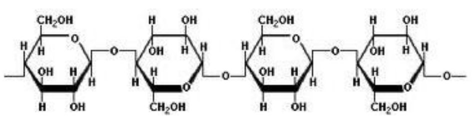
1. What is a polymer?
2. Classification of polymers
   - natural vs synthetic polymers
   - thermoplast vs thermoset polymers
   - homo-, co-, cross-linked and grafted polymers
   - polymerisation mechanism
3. Properties of polymers
   - morphology
   - glass transition temperature
4. Composition of commercial polymers
   - additives
   - residues
   - catalysts
   - oligomers
   - degradation compounds
5. Processing of polymers

NATURAL POLYMERS: polymers also exist in nature

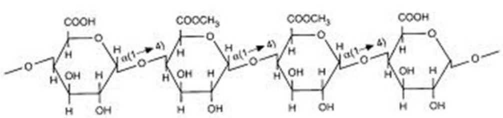
- Latex / natural rubber
- Starch
- Cellulose
- Pectin
- Silk / Wool
- DNA
- ....



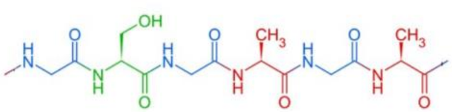
Repeating Isoprene units



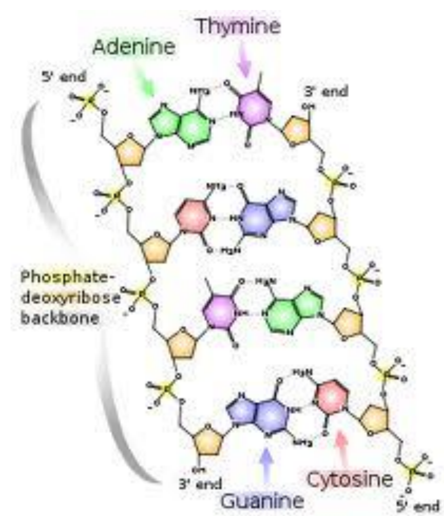
Repeating D-Glucose units



Repeating Galacturonic acid units



Repeating units of amino acids



DNA

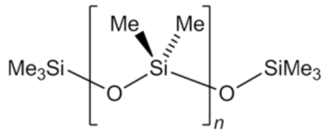
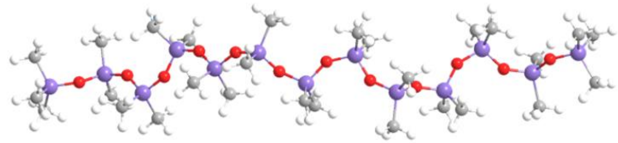
- However, most of the pharmaceutical applications are with **SYNTHETIC POLYMERS**

2. CLASSIFICATION OF POLYMERS

Synthetic polymers

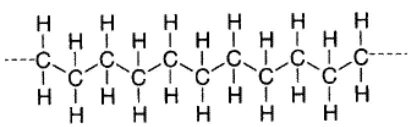
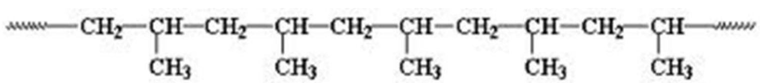
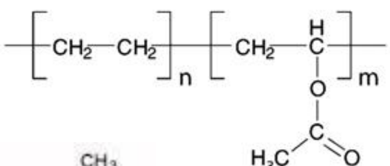
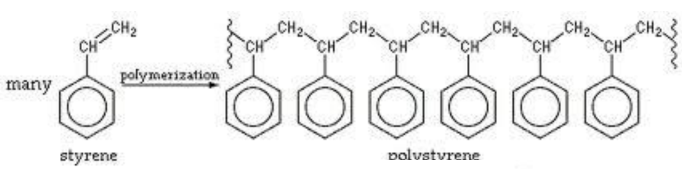
A small fraction are ***INORGANIC POLYMERS***

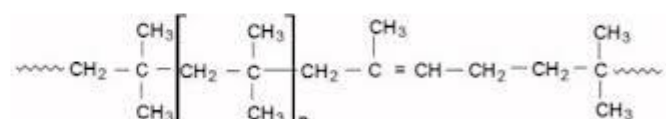
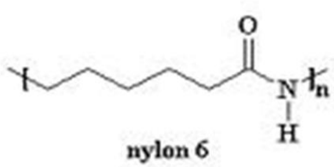
Example: Siloxanes (PolyDiMethylSiloxanes; PDMS) (SILICONE)

However, most of the polymers are ***ORGANIC POLYMERS***

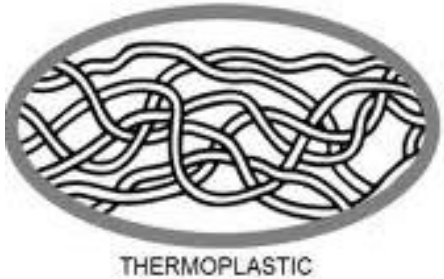
Examples: polyethylene (PE), polypropylene (PP), ethylene vinyl acetate (EVA), polystyrene (PS), Isobutylene Isoprene Rubber (IIR rubber), nylon 6, nylon 6,6,...

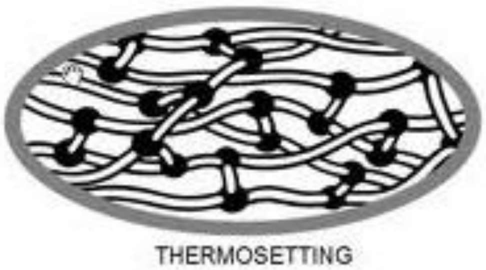



2. CLASSIFICATION OF POLYMERS

Thermoplast VS. Thermoset



"Entangled" polymer chains

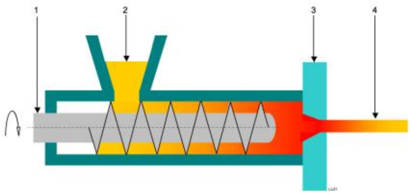


Crosslinked polymer chains

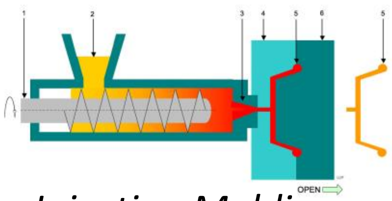
THERMOPLAST:

Polymers that soften when heated and become firm again when cooled

Giving the **final form to a container/component** is based upon this principle: extrusion, molding,...



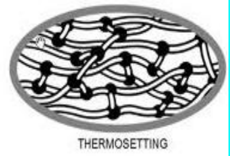
Extrusion



Injection Molding

Examples: LDPE, HDPE, PP, EVA, PTFE, PC,...

2. CLASSIFICATION OF POLYMERS



THERMOSET:

Polymers that soften when heated and molded subsequently BUT decompose when reheated (i.e. cannot be reformed after cooling)

Thermoset polymers are typically "**cross linked**" (irreversible chemical bonds formed during curing process)

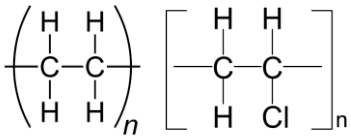
Examples: *Bakelite* *Rubbers* *Silicone tubings*

Fenol Formaldehyde Resin

Type of Polymers

HOMOPOLYMER: polymer built from a sequence of identical monomers

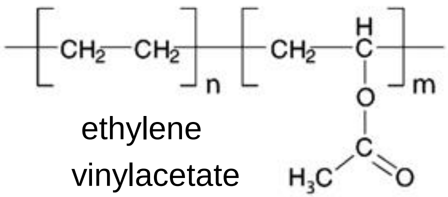
Examples: PE, PP, PVC A-A-A-A-A-A-A-A-A-A-A-A-A-A



COPOLYMER: polymer built from a sequence of *two different monomers*

Random copolymer A-B-A-A-B-B-B-A-B-A-A-A-B

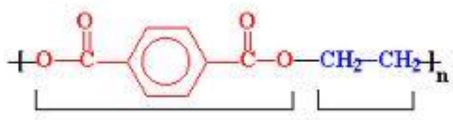
Example: Poly EVA



ethylene vinylacetate

Regular copolymer A-B-A-B-A-B-A-B-A-B-A-B-A

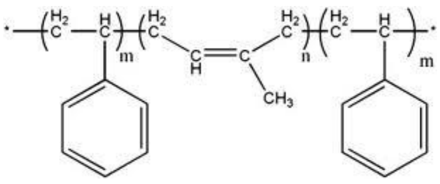
Example: PET



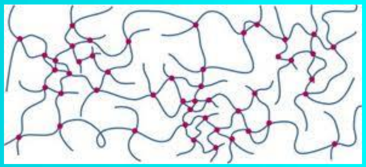
terephthalate ethylene

Block copolymer A-A-A-B-B-B-B-B-B-B-B-A-A

Example: SIS elastomer



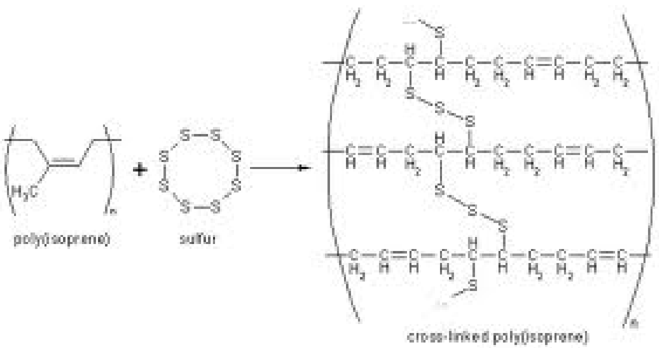
styrene isoprene styrene



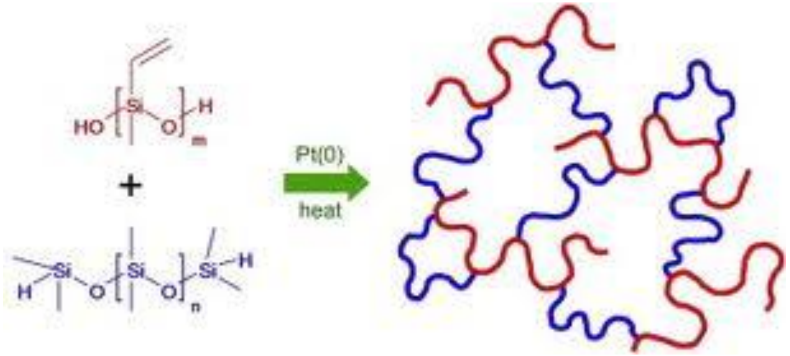
Type of Polymers

CROSS-LINKED POLYMERS

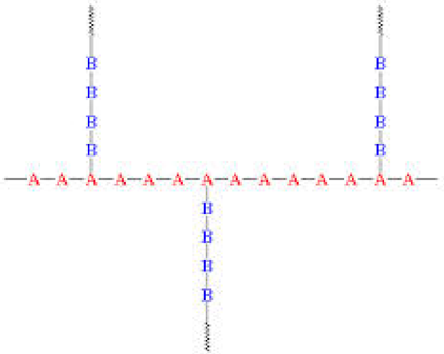
Isoprene / butadiene rubbers



Silicone rubbers (Pt-cured)



GRAFTED CO-POLYMERS

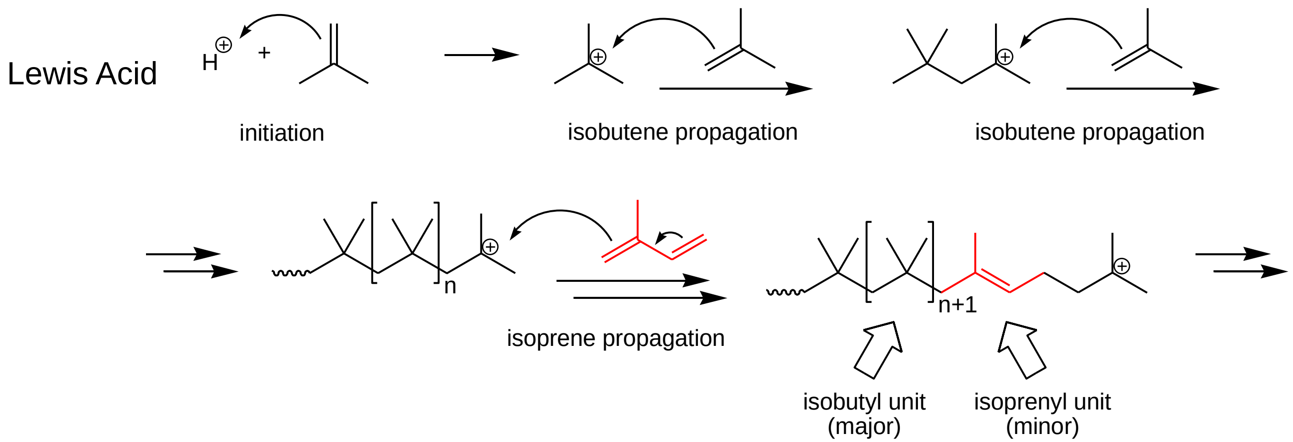


graft copolymer

Classification based upon polymerisation mechanism

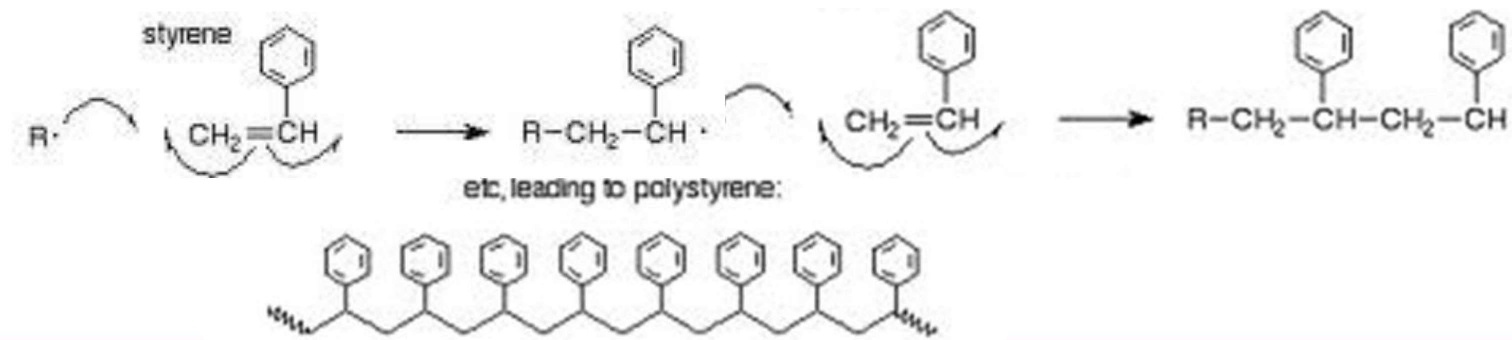
CHAIN GROWTH:

Example 1: Cationic polymerization of "butyl elastomer"



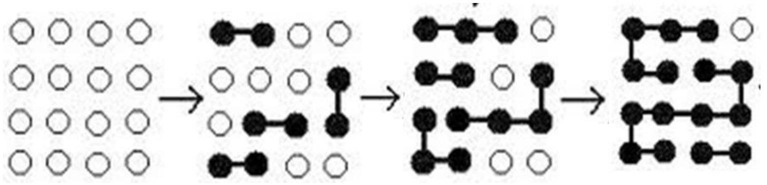
Understanding polymerization of butyl elastomer helps to understand the formation and presence of rubber oligomers

Example 2: Radical polymerization of polystyrene

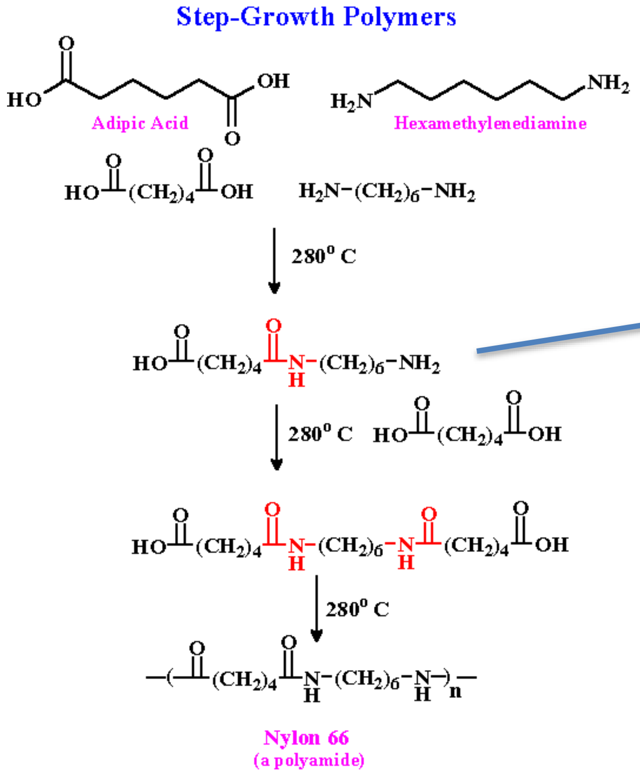


Classification based upon polymerisation mechanism

STEP GROWTH:



Example: Polycondensation – Nylon 6,6



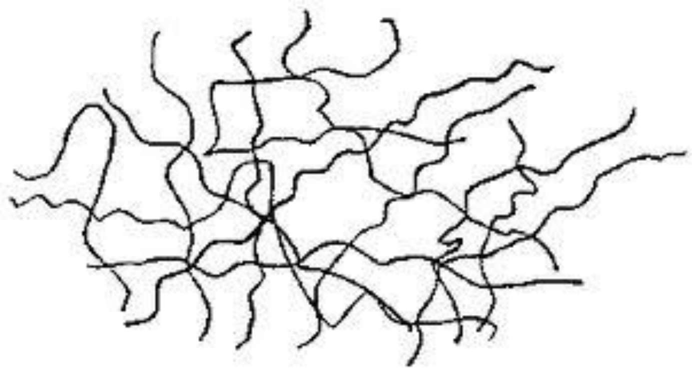
seen as an Extractable / Leachable

OVERVIEW

1. What is a polymer?
2. Classification of polymers
    - natural vs synthetic polymers
    - thermoplast vs thermoset polymers
    - homo-, co-, cross-linked and grafted polymers
    - polymerisation mechanism
3. **Properties of polymers**
    - **morphology**
    - **glass transition temperature**
4. Composition of commercial polymers
    - additives
    - residues
    - catalysts
    - oligomers
    - degradation compounds
5. Processing of polymers

1. Morphology

AMORPHOUS POLYMERS



Because of
- Irregularities in polymer structure
- Nature of the polymer
- Cross-linking (for certain polymers)

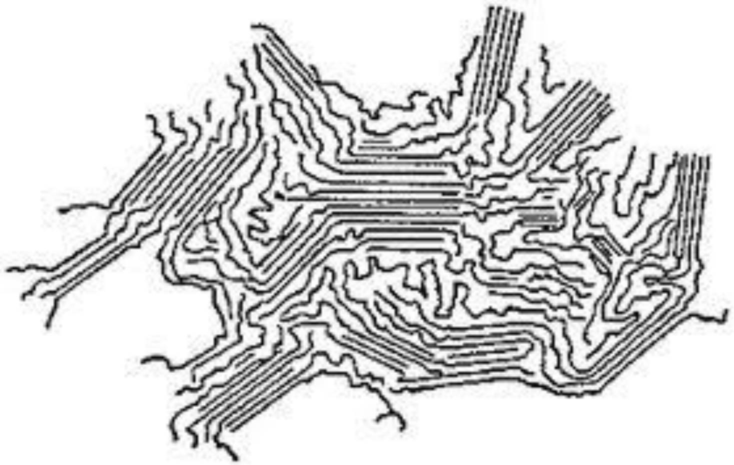
No intermolecular bonds (e.g. Hydrogen bonds, Van der Waals forces) will lead to an alignment of the polymer chains

Examples: PS, PVC, SAN, ABS, PMMA, PC, PES

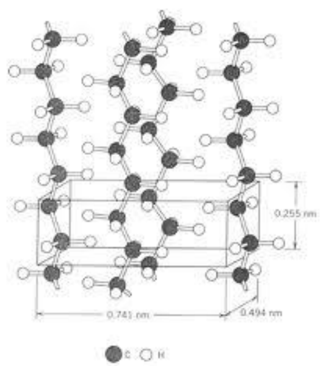
1. Morphology

(SEMI-)CRYSTALLINE POLYMERS

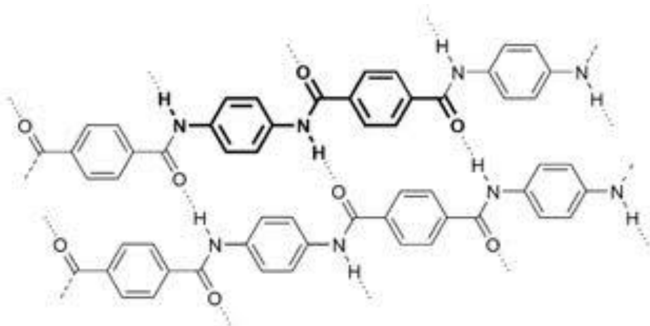
Van der Waals forces (e.g. polyolefins)
Hydrogen bonds (e.g. polyamide)
➔ Bring "alignment" in chains



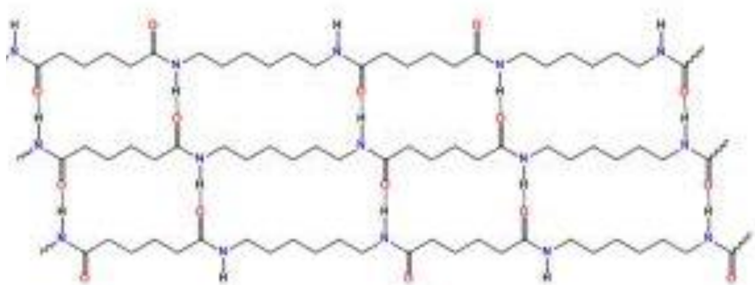
Impact of Stereochemistry of a polymer on physical properties



PE



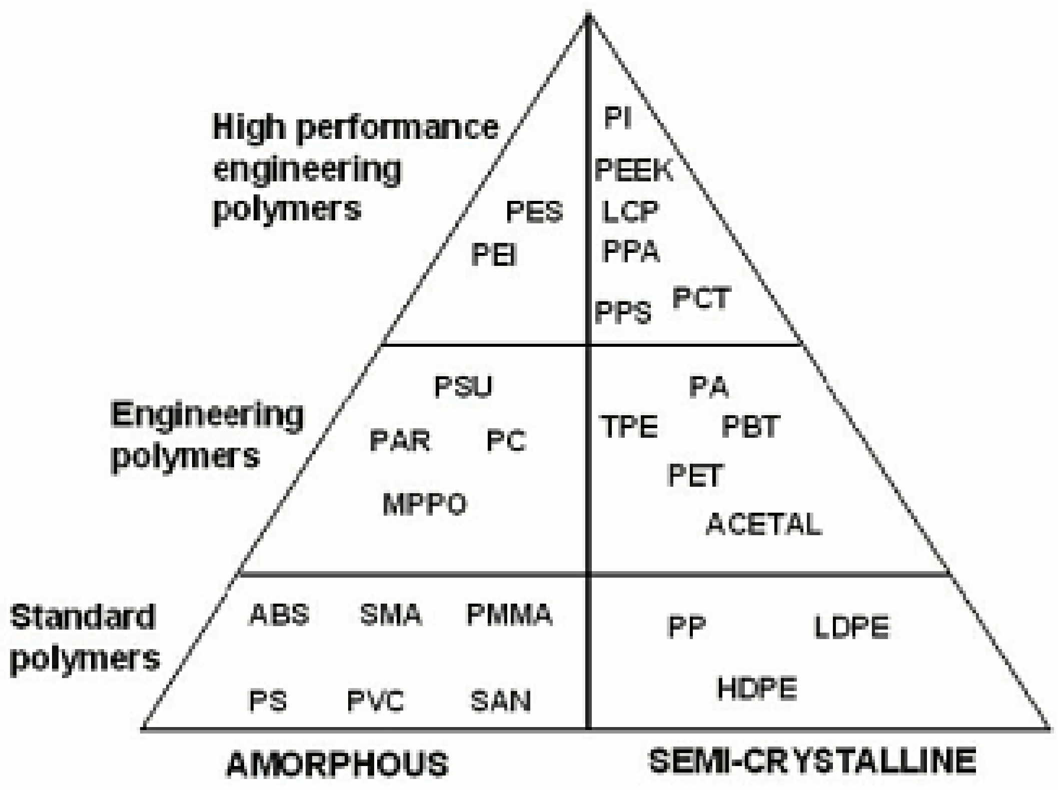
Kevlar



Nylon 6,6
(polyamide)

1. Morphology

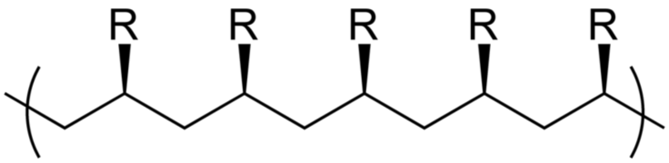
AMORPHOUS VS. CRYSTALLINE



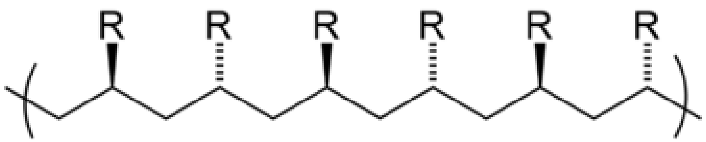
1. Morphology

AMORPHOUS VS. CRYSTALLINE

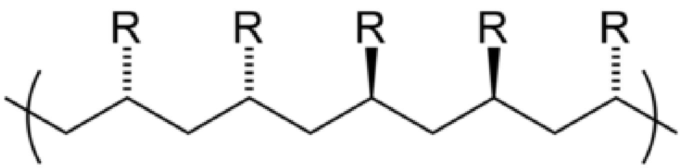
Impact of **StereoChemistry** of a polymer on physical properties



Isotactic
Typically semi-crystalline
(e.g. PP via Ziegler-Natta polymerisation)



Syndiotactic
PS: Syndiotactic PS is semi-crystalline

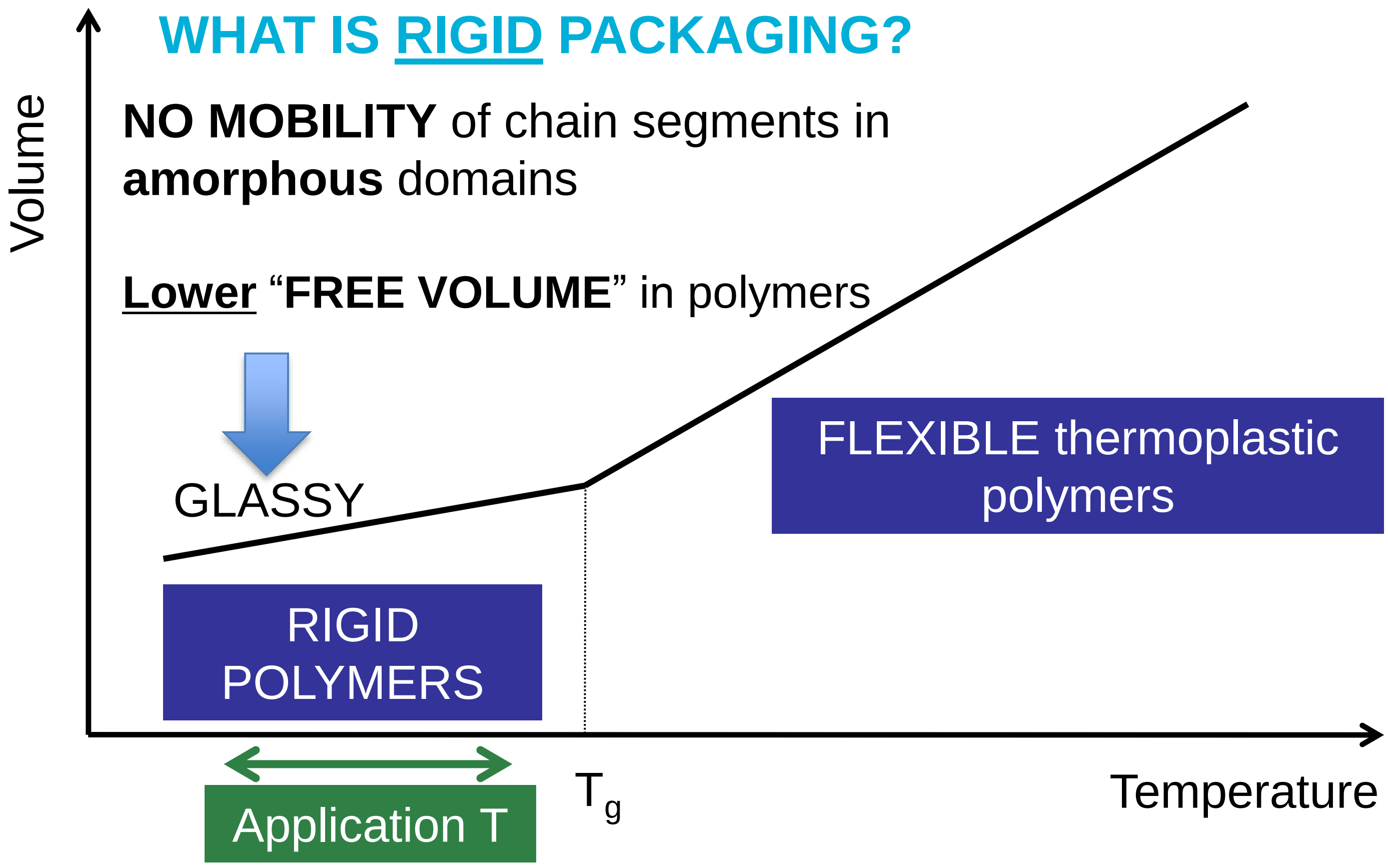


Atactic
Typically amorphous polymers
PS: Atactic PS is amorphous

TACTICITY MODULATORS, SOMETIMES FOUND AS EXTRACTABLES

2. Glas transition temperature (T_g)

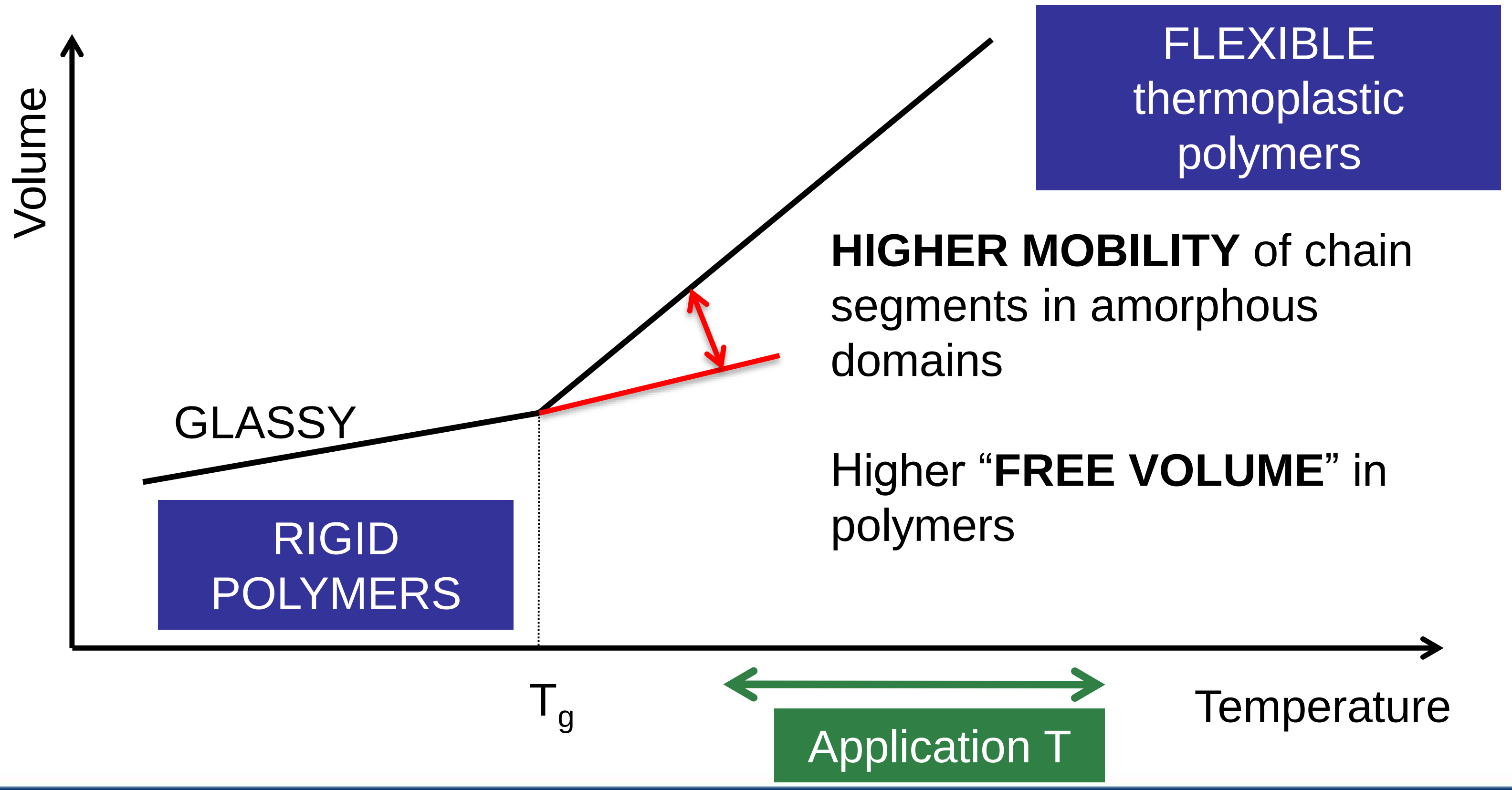
Temperature when a polymer goes from a “glassy” state (< T_g) to a “rubber” state (> T_g)



2. Glas transition temperature (T_g)

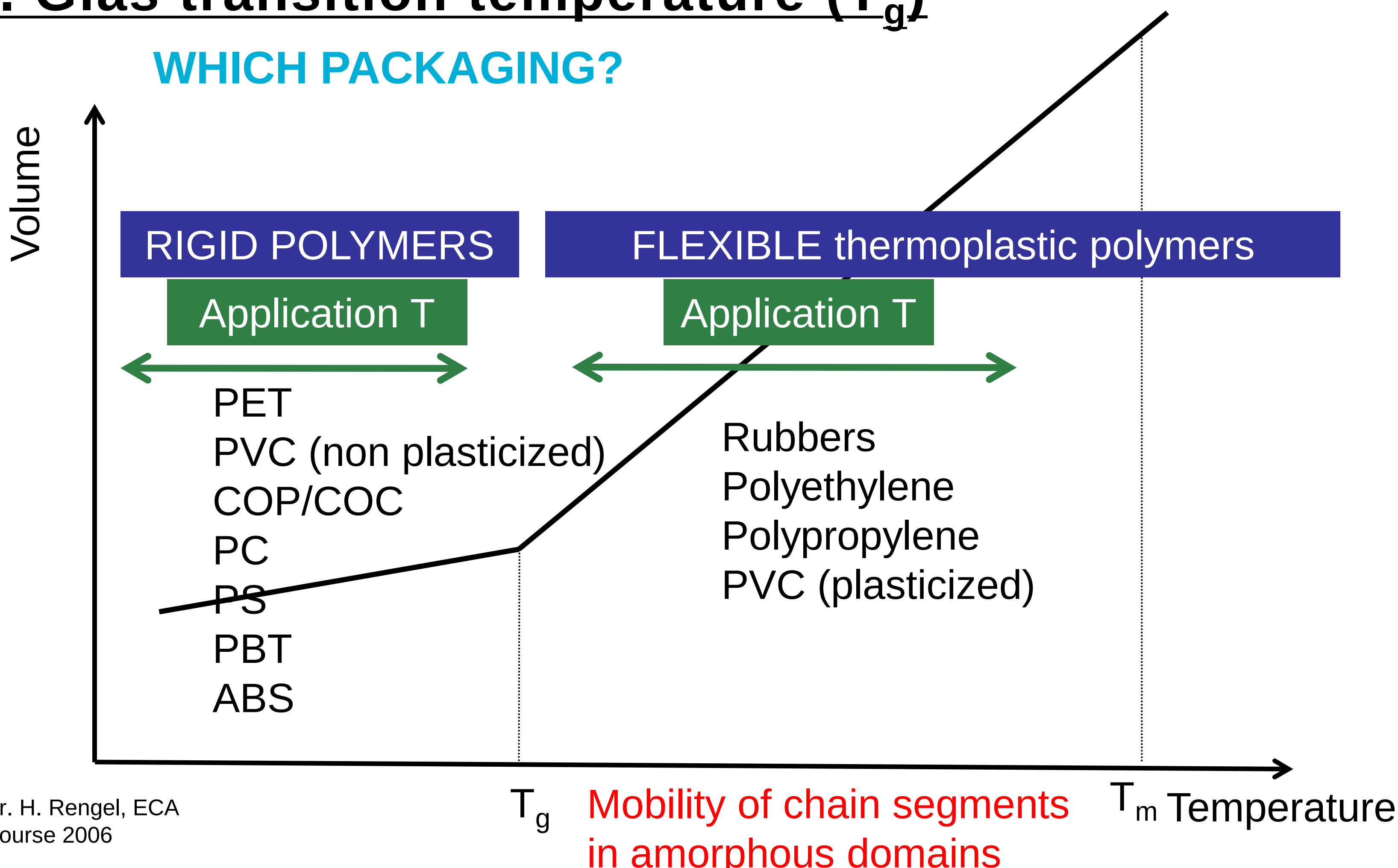
Temperature when a polymer goes from a "glassy" state ($< T_g$) to a "rubber" state ($> T_g$)

WHAT IS FLEXIBLE PACKAGING?



2. Glas transition temperature (T_g)

WHICH PACKAGING?



Dr. H. Rengel, ECA
Course 2006

2. Glas transition temperature (T_g)

Examples of T_g for different materials

LDPE	T_g = -125°C
POM	T_g = -50°C
PP	T_g = -25°C
PBT	T_g = +70°C
PVC	T_g = +81°C (non plasticized)
ABS	T_g = +110°C
PC	T_g = +150°C

The T_g of a material will also have an impact on the migration behavior of a material!

OVERVIEW

1. What is a polymer?
2. Classification of polymers
   - natural vs synthetic polymers
   - thermoplast vs thermoset polymers
   - homo-, co-, cross-linked and grafted polymers
   - polymerisation mechanism
3. Properties of polymers
   - morphology
   - glass transition temperature
4. **Composition of commercial polymers**
   - **additives**
   - **residues**
   - **catalysts**
   - **oligomers**
   - **degradation compounds**
5. Processing of polymers

4. COMPOSITION OF COMMERCIAL POLYMERS

Anti-oxidants
Plasticizers
Photostabilizers
Slip agents
Antiozonants
Coupling agents
Lubricants
Acid scavengers
Peroxides / crosslinkers
Blowing agents
Pigments / colorants
Antistatic agents
Metal chelators
Adhesives
Catalysts
Clarifying agents
Antifogging agents
Fillers

(blue: coming with some examples)

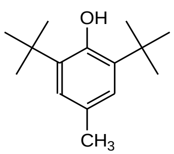
4. COMPOSITION OF COMMERCIAL POLYMERS ADDITIVES

Anti-oxidants

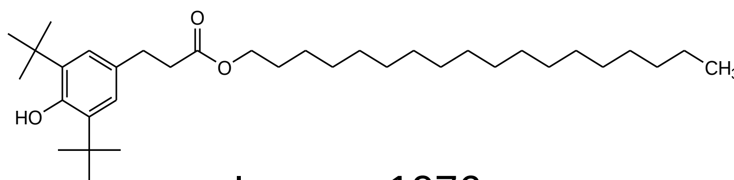
Function: assuring protection against thermal and oxidative degradation during processing and during shelf life of polymer

(*Sterically Hindered Phenols & Organic Phosphites/Phosphonates are mostly used*)

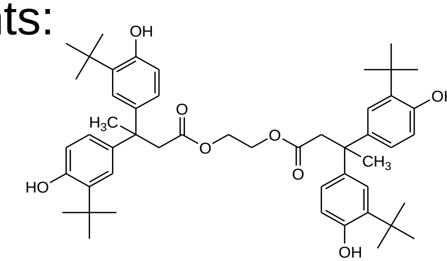
European Pharmacopoeia lists a.o. the following anti-oxidants:



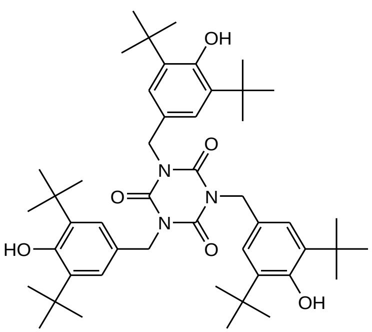
BHT



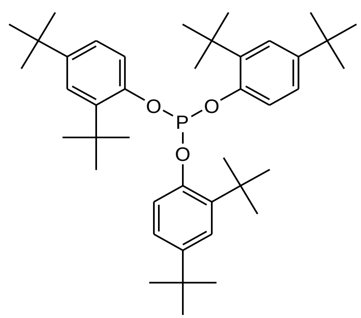
Irganox 1076



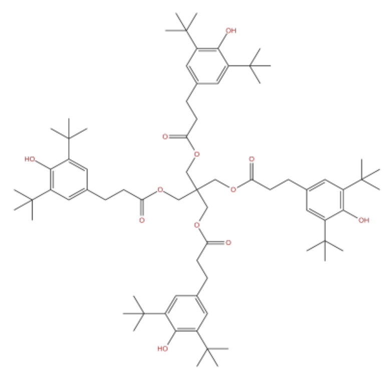
Hostanox 03



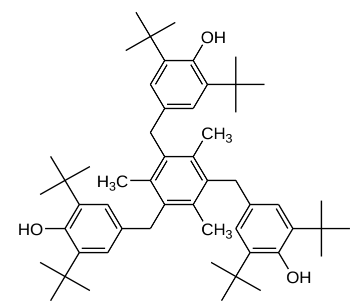
Irganox 3114



Irgafos 168



Irganox 1010



Irganox 1330

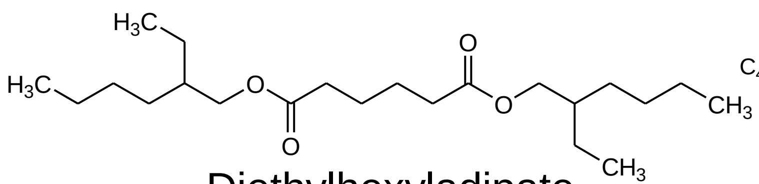
4. COMPOSITION OF COMMERCIAL POLYMERS ADDITIVES

Plasticizers

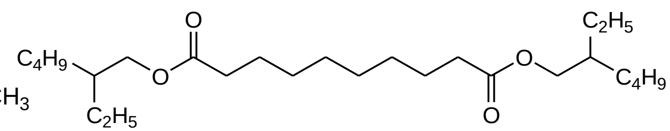
Function: gives the plastic flexibility and durability

Plasticizer requirements:

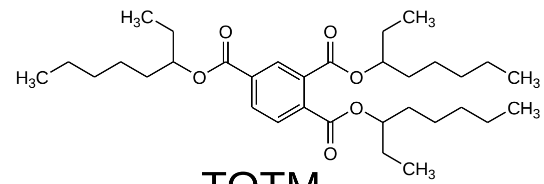
- Low water solubility (low extractibility)
- Stability to heat and light
- Low odor, taste and toxicity



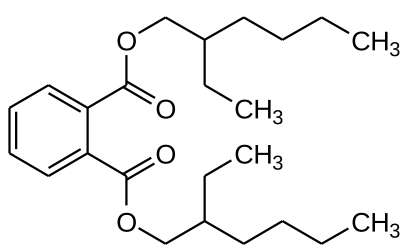
Diethylhexyladipate



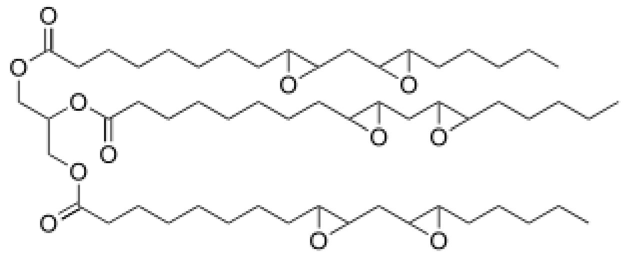
Diethylhexylsebacate



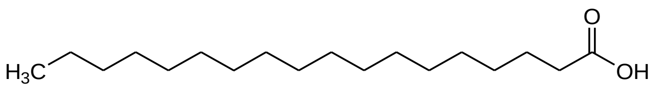
TOTM



Diethylhexylphthalate (DEHP)



ESBO

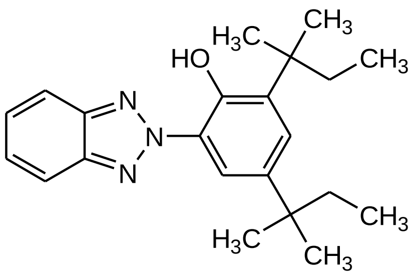


Stearic acid

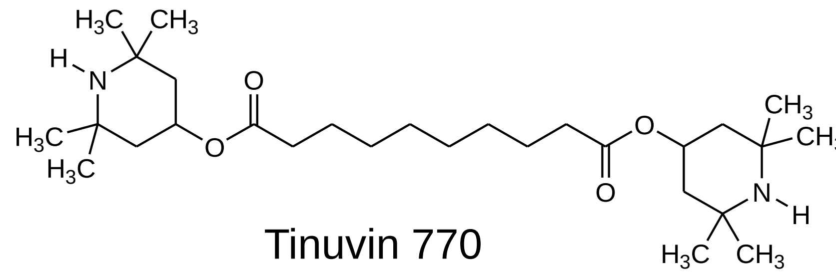
4. COMPOSITION OF COMMERCIAL POLYMERS ADDITIVES

Photostabilizers

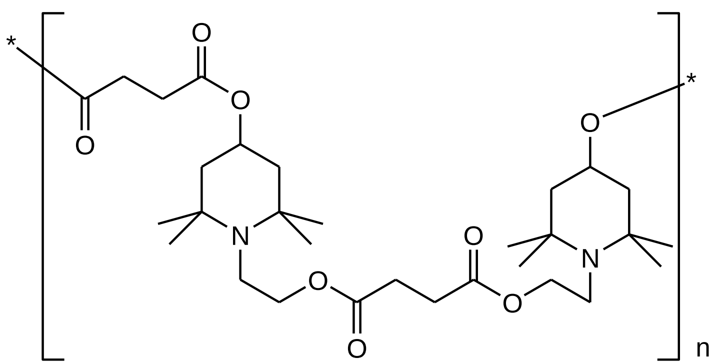
Function: protects the polymer from UV-Degradation (exposure to sunlight)



Tinuvin 328



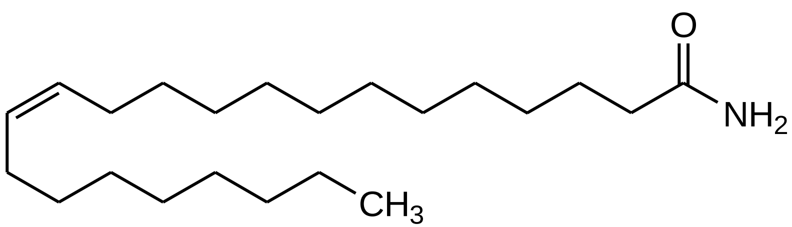
Tinuvin 770



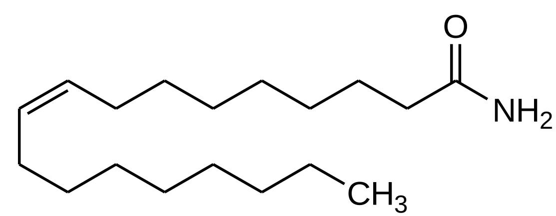
Tinuvin 622

Slip agents

Function: reduce the "friction" or "film adherence", important when producing bags from films



Erucamide (C22)



Oleamide (C18)

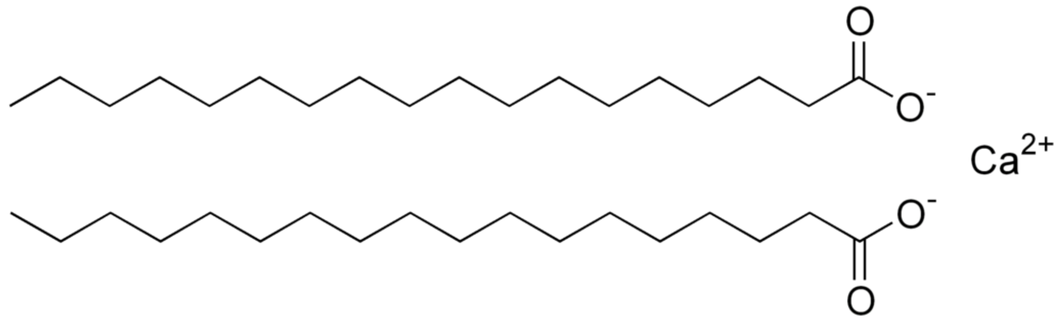
Remark:
because of their specific properties, slip agents will be widely detected as Leachables!

Acid scavengers

Function: Protects the polymer from "acid attacks" through conversion of strong acids (high degradation impact) to weak acids (low degradation impact)

Example: $Ca(Stearate)_2$ + 2HCl ➔ $CaCl_2$ + stearic acid

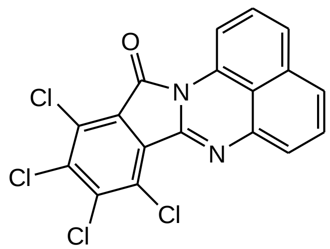
strong acid (2HCl) **weak acid** (stearic acid)



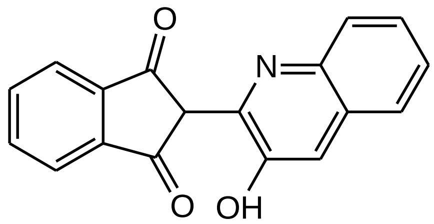
Pigments / colorants

Function: Gives the polymer / rubber the desired color (cosmetic)

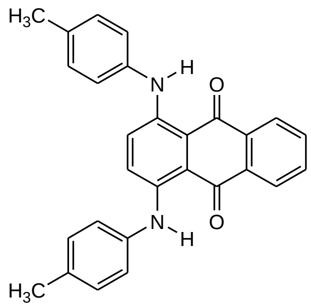
Examples: Carbon Black (PNA's!), TiO_2 (white), Fe_2O_3 (red), Pigment Green 07



Solvent Red



Solvent yellow 114

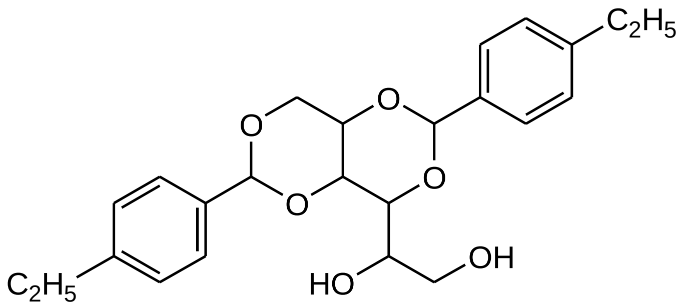


Solvent Green 03

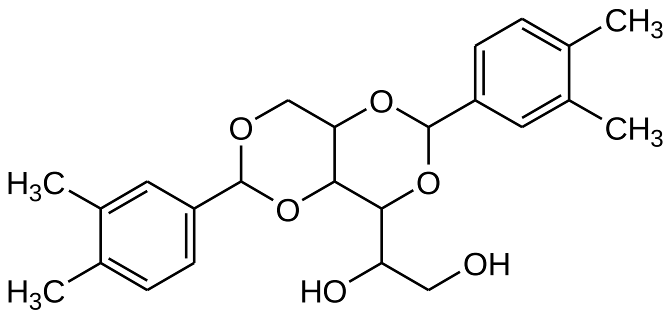
***Remark*: beware of the composition of the masterbatch!**

Clarifying agents (nucleating agents)

Function: by controlling the crystallisation (nucleation) when cooling off polypropylene, PP becomes transparent instead of opaque



NC-4

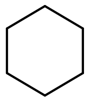


Millad 3988

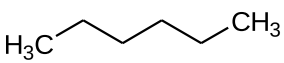
4. COMPOSITION OF COMMERCIAL POLYMERS RESIDUES

Residues: Residues from the production process (non-limitative)

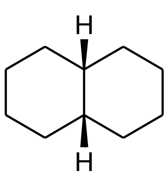
Solvents



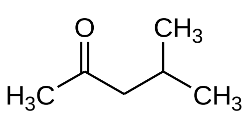
Cyclohexane



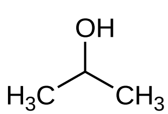
Hexane



DHN

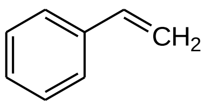


MIBK

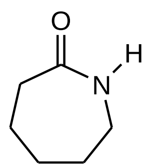


IPA

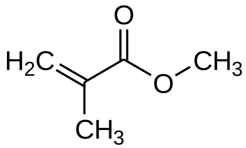
Monomers



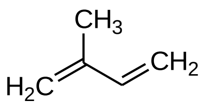
Styrene



Caprolactam



Methyl methacrylate



Isoprene

Catalysts

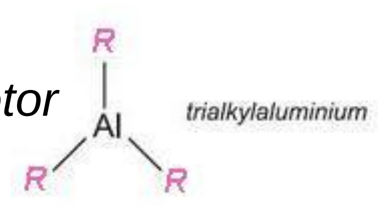
Titanium
Zirkonium
Cobalt
Aluminum
Iron
Hafnium
...

Catalysts:

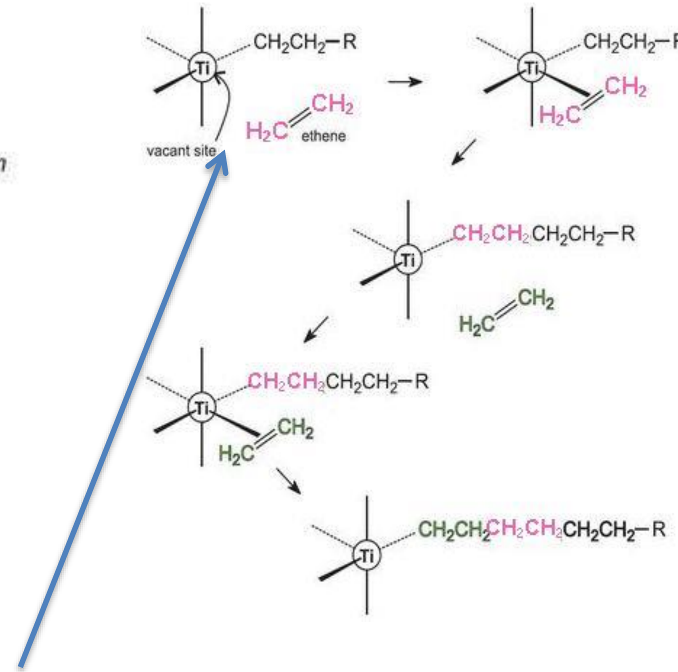
Function: assists in a very efficient polymerization process

Examples:

promotor

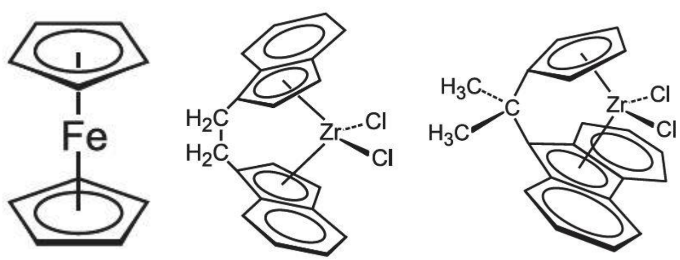


Ziegler-Natta Catalyst



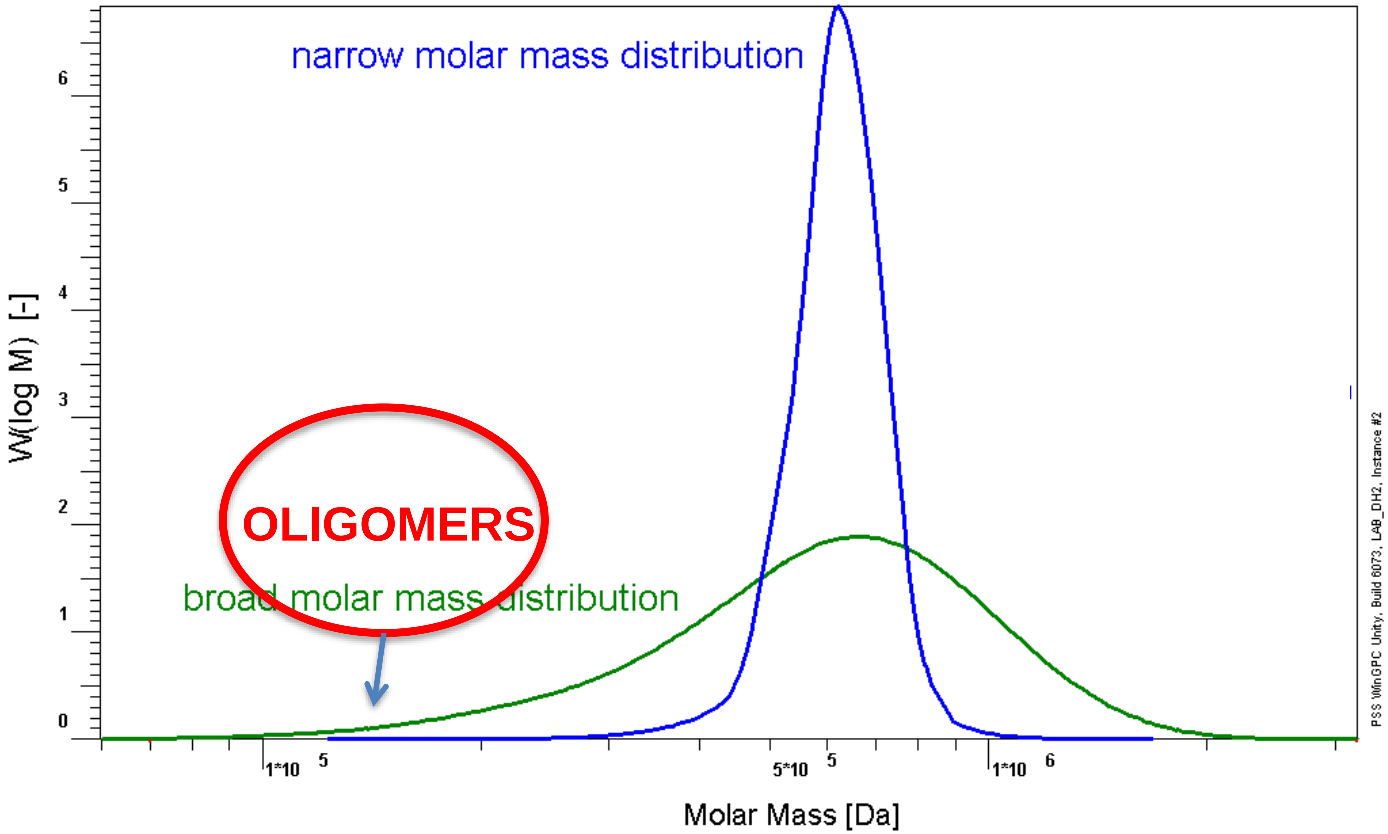
Ti-catalyst

Metallocenes
(stereospecific catalysts)



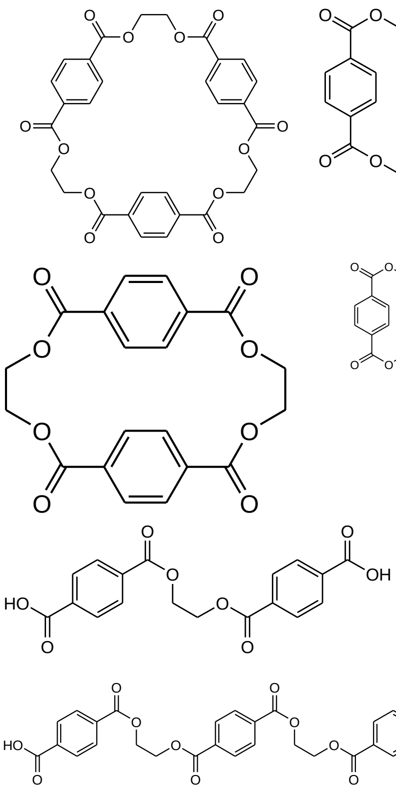
The alkene monomer attaches itself to an empty coordination site on the titanium atom and this alkene molecule then inserts itself into the carbon-titanium bond to extend the alkyl chain. This process then continues, thereby forming a linear polymer

Oligomers:

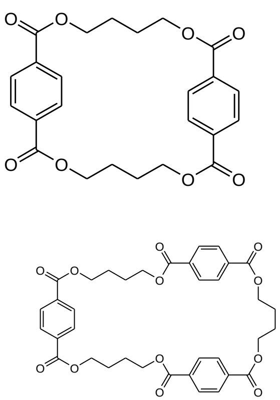

narrow molar mass distribution
OLIGOMERS
broad molar mass distribution
W(log M) [-]
Molar Mass [Da]
0
1
2
3
4
5
6
1*10 5
5*10 5
1*10 6
PSS WinGPC Unity, Build 6073, LAB_DH2, Instance #2

Oligomers: examples

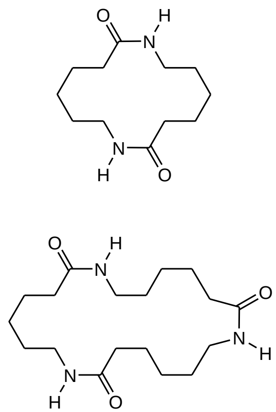
PET



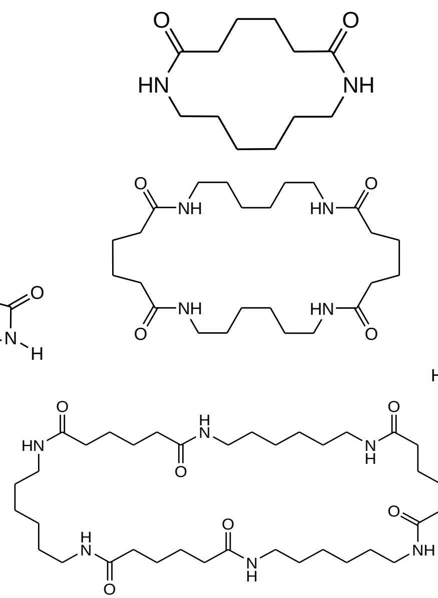
PBT



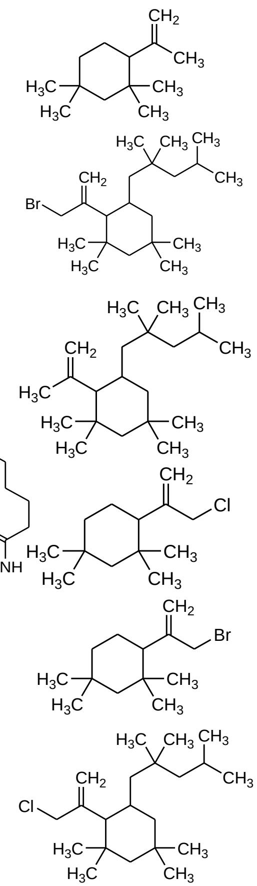
Nylon 6



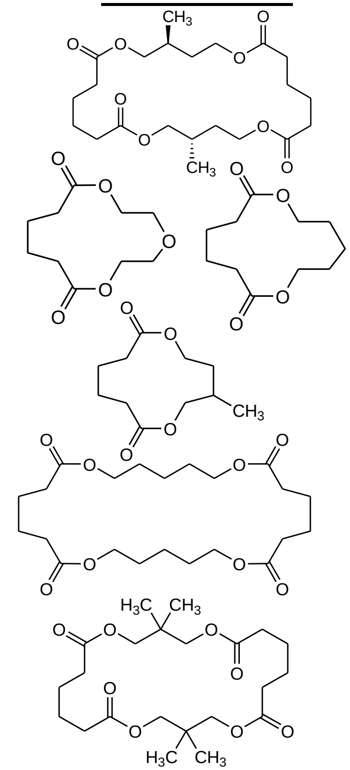
Nylon 6,6



Butyl Rubber



Polyester adhesive



Other typical oligomers from Silicone, PP, PE, adhesives,...

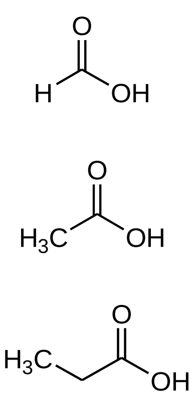
Polymer degradation compounds:

Origin: Oxidative degradation of the polymers

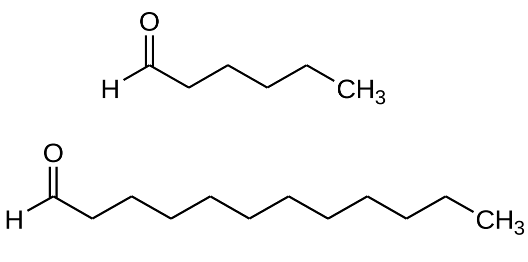
(when the polymer is not properly stabilized via anti-oxidants)

Example of polymer degradation compounds from **polypropylene**

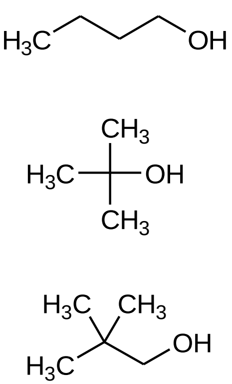
Acids



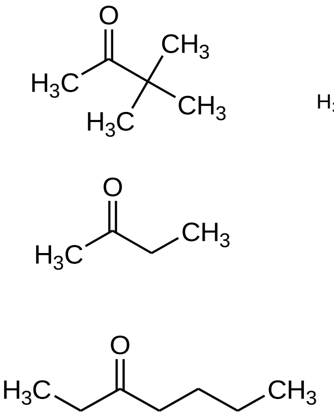
Aldehydes



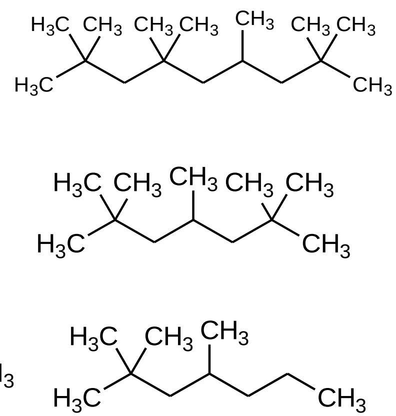
Alcohols



Ketones



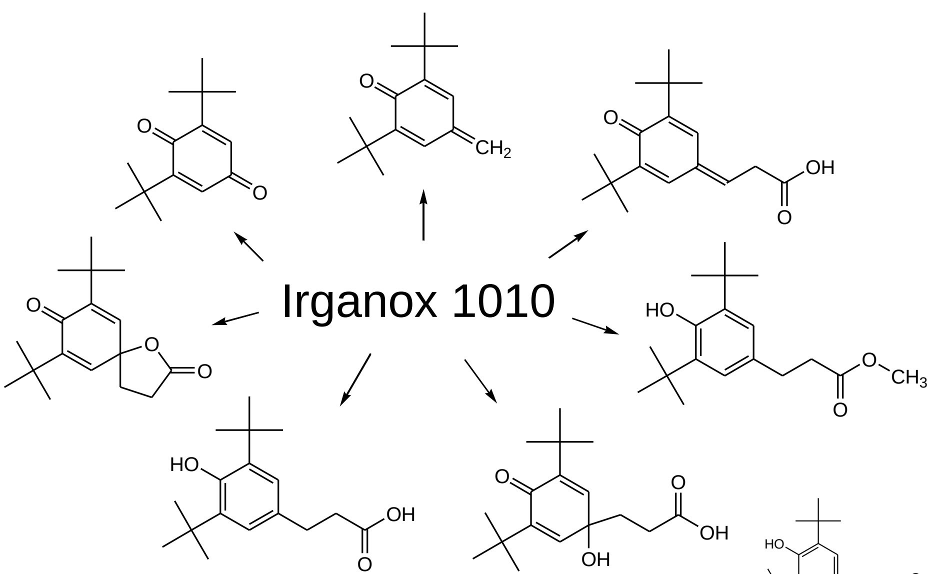
Polymer fragments



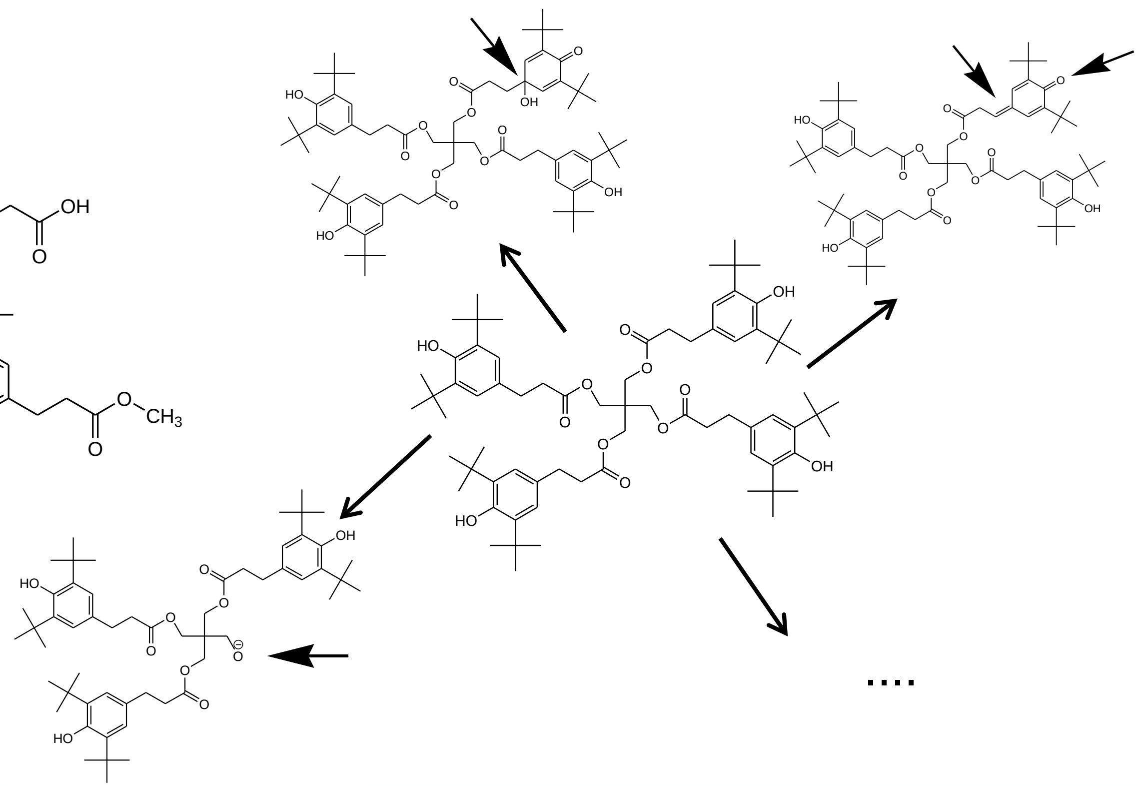
Polymer additive degradation compounds:

Example of polymer additive degradation compounds from **Irganox 1010**

SMALL degradation Compounds



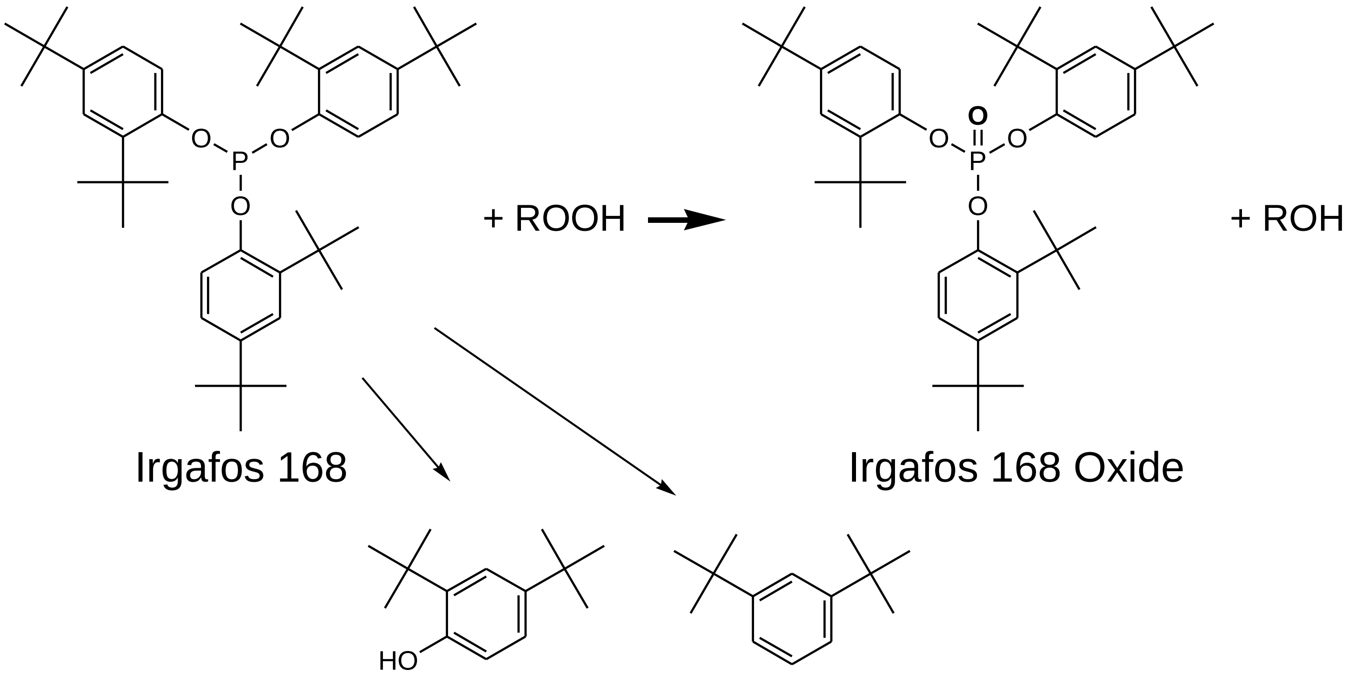
LARGE degradation Compounds



....

Polymer additive degradation compounds

Example of polymer additive degradation compounds from **Irgafos 168**



(Remark: also other degradation compounds for Irgafos 168 are known)

5. PROCESSING OF POLYMERS

Name(s)	Formula	Monomer	Examples of Uses
Polyethylene low density (LDPE)	$–(CH_2\text{-}CH_2)_n–$	ethylene $CH_2{=}CH_2$	Films for bags, multilayer contact film
Polyethylene high density (HDPE)	$–(CH_2\text{-}CH_2)_n–$	ethylene $CH_2{=}CH_2$	Bottles, caps
Polypropylene (PP) different grades	$–[CH_2\text{-}CH(CH_3)]_n–$	propylene $CH_2{=}CHCH_3$	Bottles, caps
Poly(vinyl chloride) (PVC)	$–(CH_2\text{-}CHCl)_n–$	vinyl chloride $CH_2{=}CHCl$	Bags, tubings
Polystyrene (PS)	$–[CH_2\text{-}CH(C_6H_5)]_n–$	styrene $CH_2{=}CHC_6H_5$	Secondary packaging
Polytetrafluoroethylene (PTFE, Teflon)	$–(CF_2\text{-}CF_2)_n–$	tetrafluoroethylene $CF_2{=}CF_2$	Containers, seals, tubes, tubings, “inert” coatings,…
Poly(methyl methacrylate) (PMMA)	$–[CH_2\text{-}C(CH_3)CO_2CH_3]_n–$	methyl methacrylate $CH_2{=}C(CH_3)CO_2CH_3$	Implantable lenses (IOL)
Poly(vinyl acetate) (PVAc)	$–(CH_2\text{-}CHOCOCH_3)_n–$	vinyl acetate $CH_2{=}CHOCOCH_3$	Multilayer films
cis-Polyisoprene natural rubber	$–[CH_2\text{-}CH{=}C(CH_3)\text{-}CH_2]_n–$	isoprene $CH_2{=}CH\text{-}C(CH_3){=}CH_2$	Rubbers

6. TIME FOR QUESTIONS