SBOE-35/SBOE-45

Polymer Science & Technology

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Polymer Science & Technology

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Course Content List

- Introduction
- Chemistry of Polymer Synthesis
- Polymer Reaction Kinetics
- Physical Properties and Characterization of Polymers
- Effect Of Structure on Polymer Properties
- Organic Polymer
- Introduction To High Performance Polymer
- Composite And their Processing

INTRODUCTION OF POLYMERS

- Polymers are complex and giant molecules usually with carbons building the backbone, different from low molecular weight compounds.
- The small individual repeating units/moleules are known as monomers(means single part).
- Imagine that a monomer can be represented by the letter **A**. Then a polymer made of that monomer would have the structure:

  -A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-
  A-A

Ref: Polymer Science Versa *etal*

INTRODUCTION OF POLYMERS

For detail classification I refer you to follow the hyperlink below and take the note by pausing the video.

https://youtu.be/YduOEGBtNfo

KINETICS of POLYMERIZATION REACTION

1. **For Free radical/addition/Chain growth polymerization you follow My class note or You may also follow the link below :**
2. https://youtu.be/Cw3NLcsMCwI
3. **For cationic polymerization you may follow as said before:**
4. https://youtu.be/uomkZ1VdvO8
5. **For anionic Polymerization follow the link below:**
6. https://youtu.be/aWc5wBDCxy8

Physical Properties and Characterization of Polymer

Number Average & Weight Molecular Mass

Follow my class notes and the hyperlink as below:

1. For Number Average Molecular Mass :
2. https://youtu.be/4Qd3lC8npTc
3. For weight average Molecular mass:
4. https://youtu.be/YywmrDheOno

For Polydispersity Index follow the link below:

https://youtu.be/QQwe8vmfTuU

You may also see this video as below:

https://youtu.be/GqebFU4yG1g

Physical Properties and Characterization of Polymer

Problem 1: To improve processing properties, an equal weight of low molecular mass nylon 6 (degree of polymerization n = 100) is blended with a moulding grade of nylon 6 (n = 500). Assuming both materials are monodisperse, what will be:

1. The weight-average molecular mass,
2. The number-average molecular mass,
3. The dispersion of the blend?

For the solution follow the link below:

https://www.open.edu/openlearn/science-maths-technology/science/chemistry/introduction-polymers/content-section-2.6

Effect of Structure on Polymer Properties
(Structure-property relationship)

The Structure of the polymers depends upon:

a. Size and shape of the polymer chain .
b. Chemical nature of the monomers.

The Structure of the polymers further effects the physical and mechanical properties of polymers

- ❖ Strength
- ❖ Crystallinity
- ❖ Elasticity
- ❖ Non-elastic Nature of Fibers
- ❖ Plastic deformation
- ❖ Chemical Resistivity

Effect of Structure on Polymer Properties
(Structure-property relationship)

STRENGTH:

The tensile strength of a material quantifies how much stress the material will endure before suffering permanent deformation.

For example, a rubber band with a higher tensile strength will hold a greater weight before snapping A candle and Polyethylene (PE) have basically the same molecular structure. The chain length of the candle is just much shorter than that of the PE. If you bend a bar of PE in half – it will bend, if you bend a candle in half, it will fracture.

NB: For a polymer to be commercially useful , It should have low melt viscosity, high tensile strength and impact strength (What is the tensile strength of plastic?)

Effect of Structure on Polymer Properties
(Structure-property relationship)

CRYSTALLINITY:

Amorphous **polymers** can be defined as **polymers** that do not exhibit any crystalline structures in X-ray or electron scattering experiments. They form a broad group of materials, including glassy, brittle and ductile **polymers** (what is an Amorphous Polymer?)

Example: Thermoplastics (Polystyrene, ABS)

Crystalline Polymer:

Crystallinity defines the degree of long-range order in a material, and strongly affects its properties. The more crystalline a **polymer**, the more regularly aligned its chains.

Examples of semi-crystalline **polymers** are linear polyethylene (PE), polyethylene terephthalate (PET), polytetrafluoroethylene (PTFE) or isotactic.

Factor Affecting the Crystallinity:

- Length of the chain: Long chain (high degree of polymerisation) are less likely to crystalize.
- Branching:Branched chains are less likely to crystalize

Effect of Structure on Polymer Properties
(Structure-property relationship)

Factor Affecting the Crystallinity:

❖ Copolymer :

❑ Random copolymer does not show crystallinity.
❑ Block copolymer does not show crystallinity.
❑ Graft copolymer does not show crystallinity.
❑ Alternating copolymer shows the crystallinity

❖ Tacticity or storeoisomerism:

❑ Atactic does not show crystallinity.
❑ Syndiotactic show crystallinity.
❑ Isotactic show crystallinity.

Plasticizers :

Low molecular weight additives to a polymer to prevent crystallization by keeping chains separated from one another.

I have a question for you !!
What are the factors affecting the Crystallinity in Polymer?

ORGANIC POLYMER

A polymer is a high molar mass molecular compound made up of many repeating chemical units.

Naturally occurring Organic polymers:

- Proteins
- Nucleic acids
- Cellulose
- Rubber

Synthetic Organic polymers

- Nylon
- Dacron
- Lucite

Stereoisomers of Organic Polymers :
Look at the hyperlink of Video for Stereospecific polymer
https://youtu.be/hKMnnwlCyT8

Ref: The McGraw-Hill Companies, Inc.

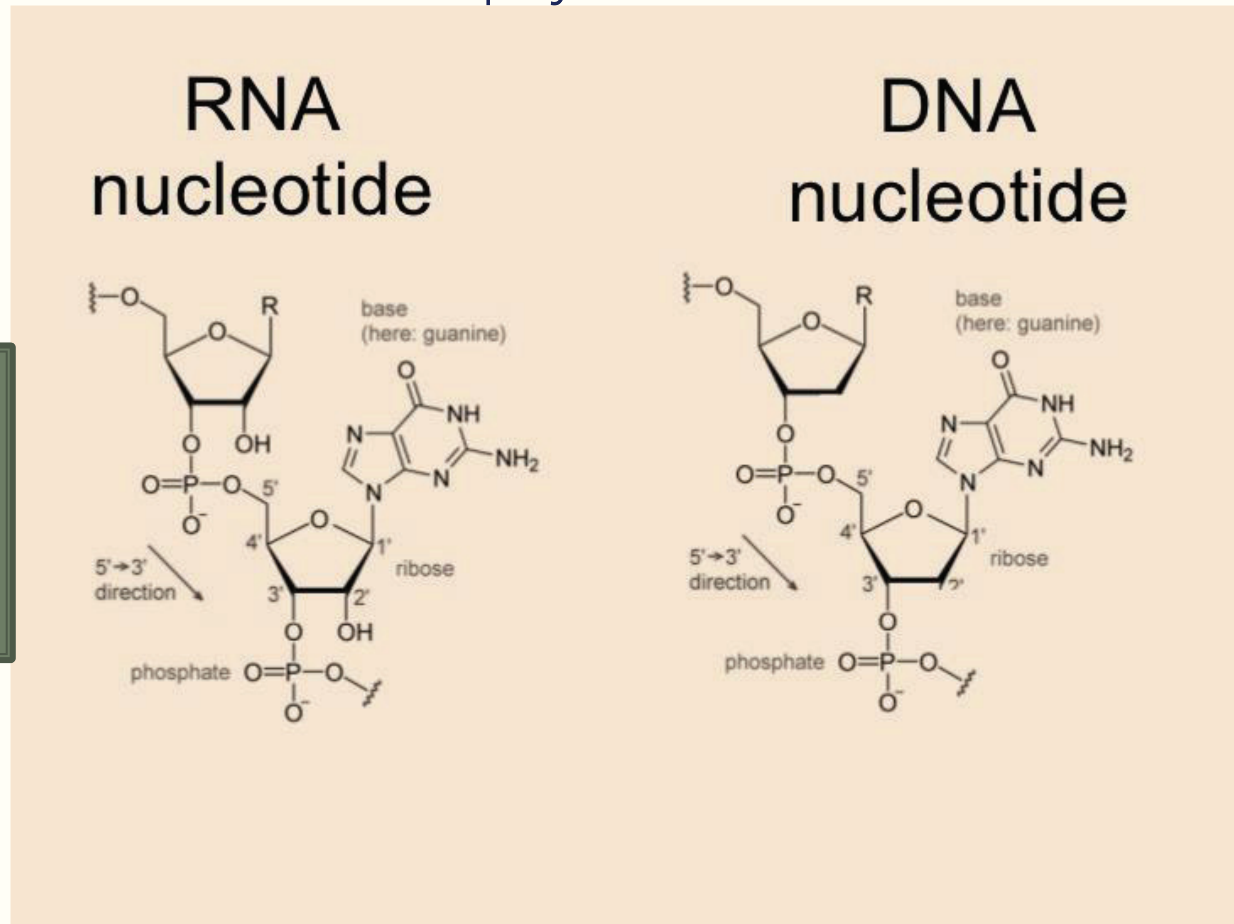
BIO- POLYMER

Biopolymers are natural polymers produced by living organisms. In biopolymers the monomeric units covalently bonded to form larger structures. here are three main classes of biopolymers, classified according to the monomeric units used and the structure of the biopolymer formed:

- Polynucleotides (i.e. RNA and DNA)
- Polypeptides
- Polysaccharides

Key Function of Polynucleotides:

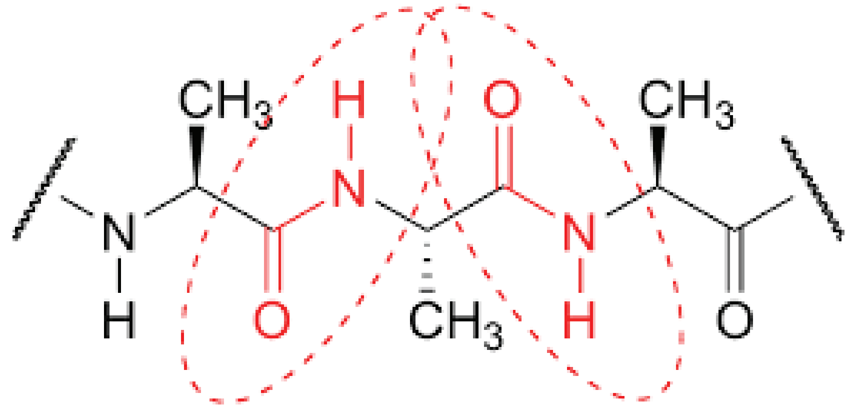
DNA and RNA perform different functions in humans. DNA is responsible for storing and transferring genetic information, while RNA directly codes for amino acids and acts as a messenger between DNA and ribosomes to make proteins



BIO- POLYMER

Polypeptides:

A **polypeptide** is a chain of amino acids. Amino acids bond together with peptide bonds in order to form a **polypeptide**. The n-terminal (amino terminal) is located at one end of the **polypeptide** while the c-terminal (carboxyl terminal) is located at its other end.



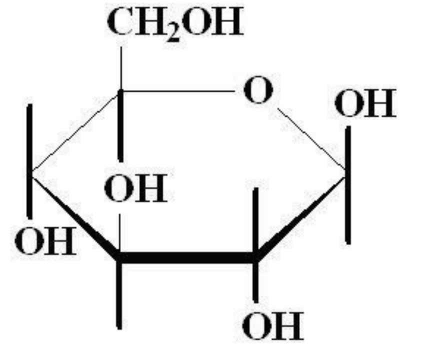
peptide bonds in a polypeptide

Key Function:
Peptides are important in biology, chemistry, and medicine because they are building blocks of hormones, toxins, proteins, enzymes, cells, and body tissues

BIO- POLYMER

Polysaccharides

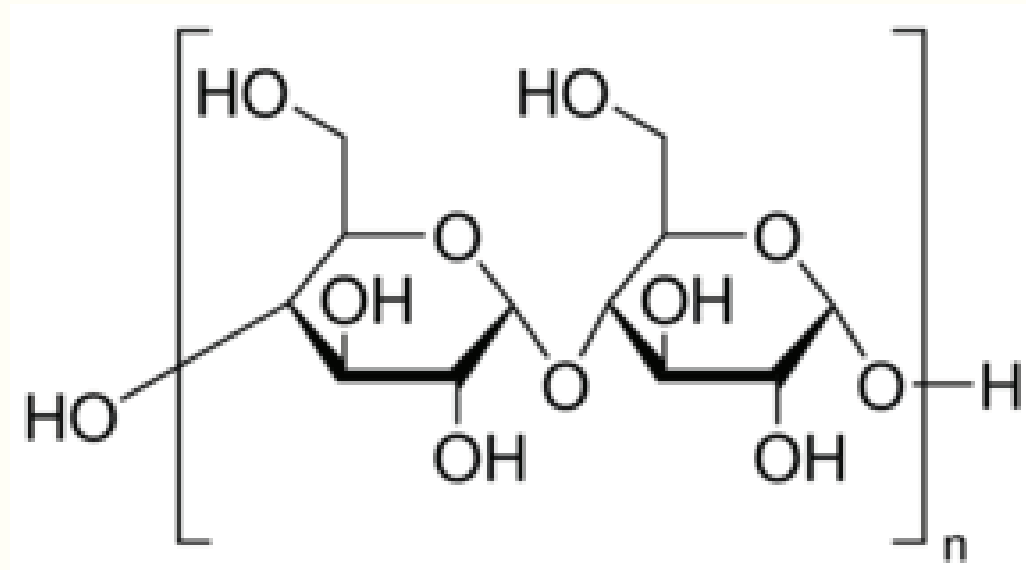
- Polysaccharides are polymers of D-glucose
- Important polysaccharides are:
  - Starch (Amylose and Amylopectin)
  - Glycogen
  - Cellulose
  - Chitin



D-Glucose

BIO- POLYMER

- The starch molecule consists of many glucose units joined by glycosidic bonds. It is produced by all vegetables as an energy store.
- A perfect raw material as a substitute for fossil-fuel components in numerous chemical applications such as plastics, detergents, glues etc



Glycogen

Glycogen is a polysaccharide of glucose that serves as a form of energy storage in fungi and animals. The polysaccharide structure of glucose shows the primary storage form of glucose in the body. Glycogen is made and stored in the cells of liver and muscles that are hydrated with the four parts of water. It acts as the secondary long-term energy storage. Muscle glycogen is quickly converted into glucose by muscle cells and liver glycogen that converts into glucose for use throughout the body which includes the central nervous system.

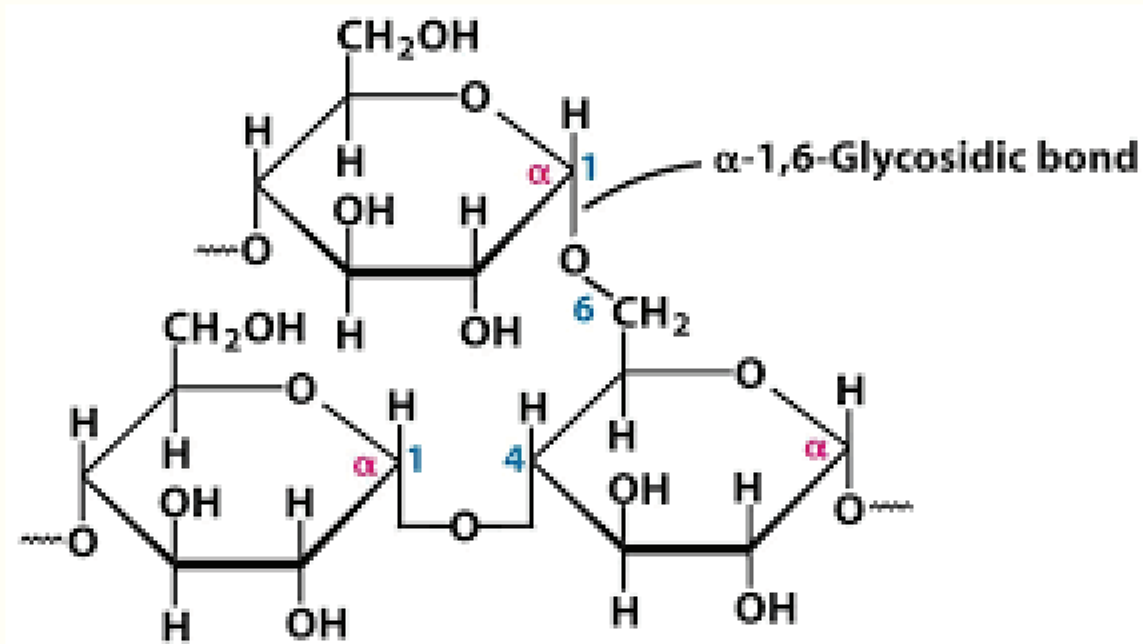
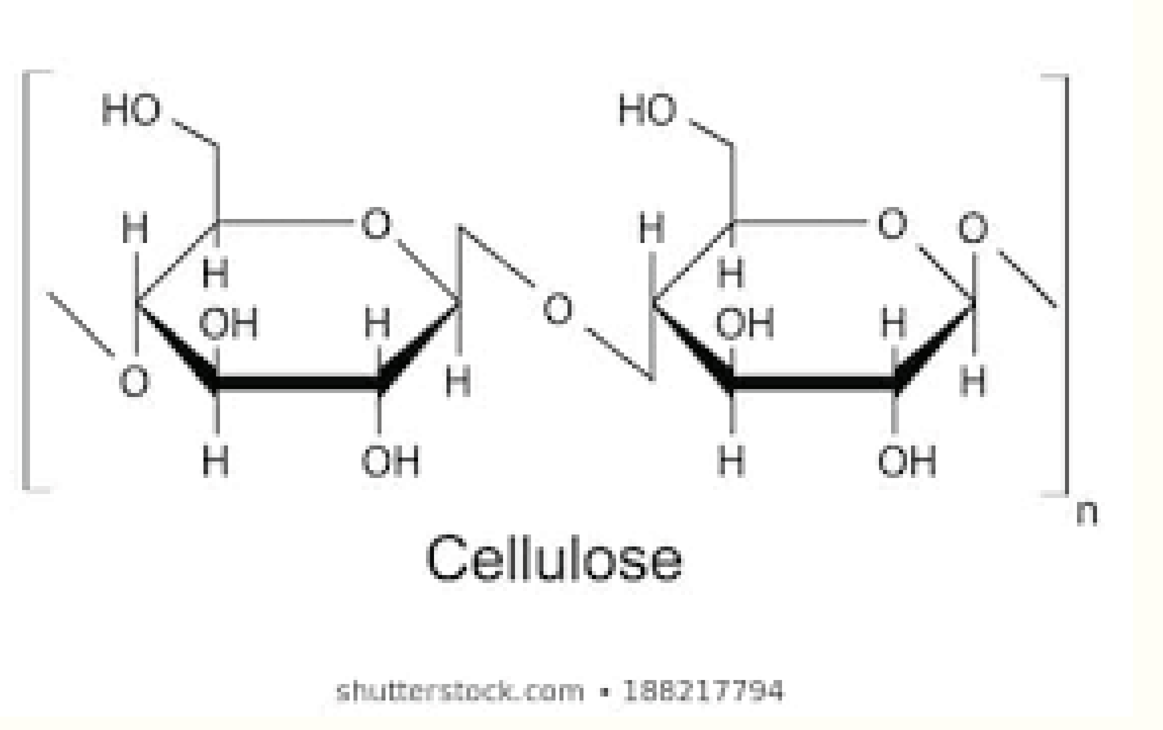


Figure 11.13

Cellulose

Cellulose is a linear polysaccharide polymer with many glucose monosaccharide units. The acetal linkage is beta which makes it different from starch. ... The structure of cellulose consists of long polymer chains of glucose units connected by a beta acetal linkage



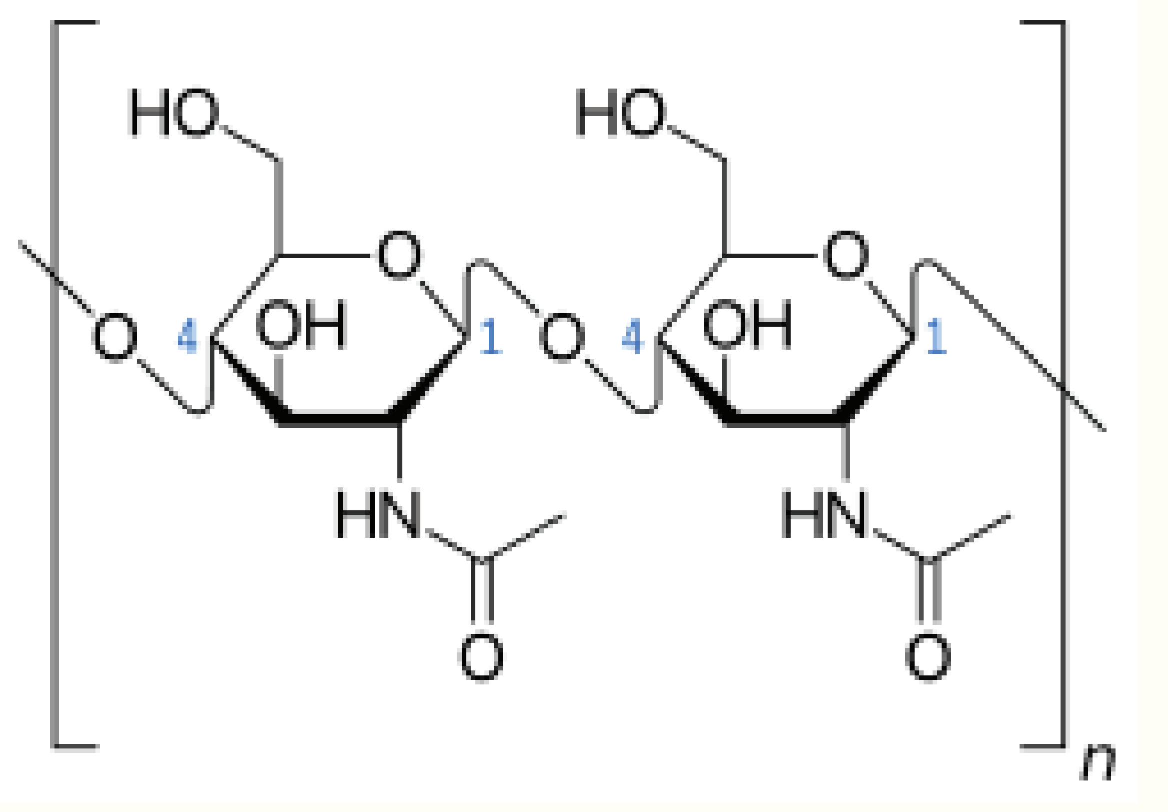
Key Role:

Cellulose is mainly used to produce paperboard and paper.

Chitin

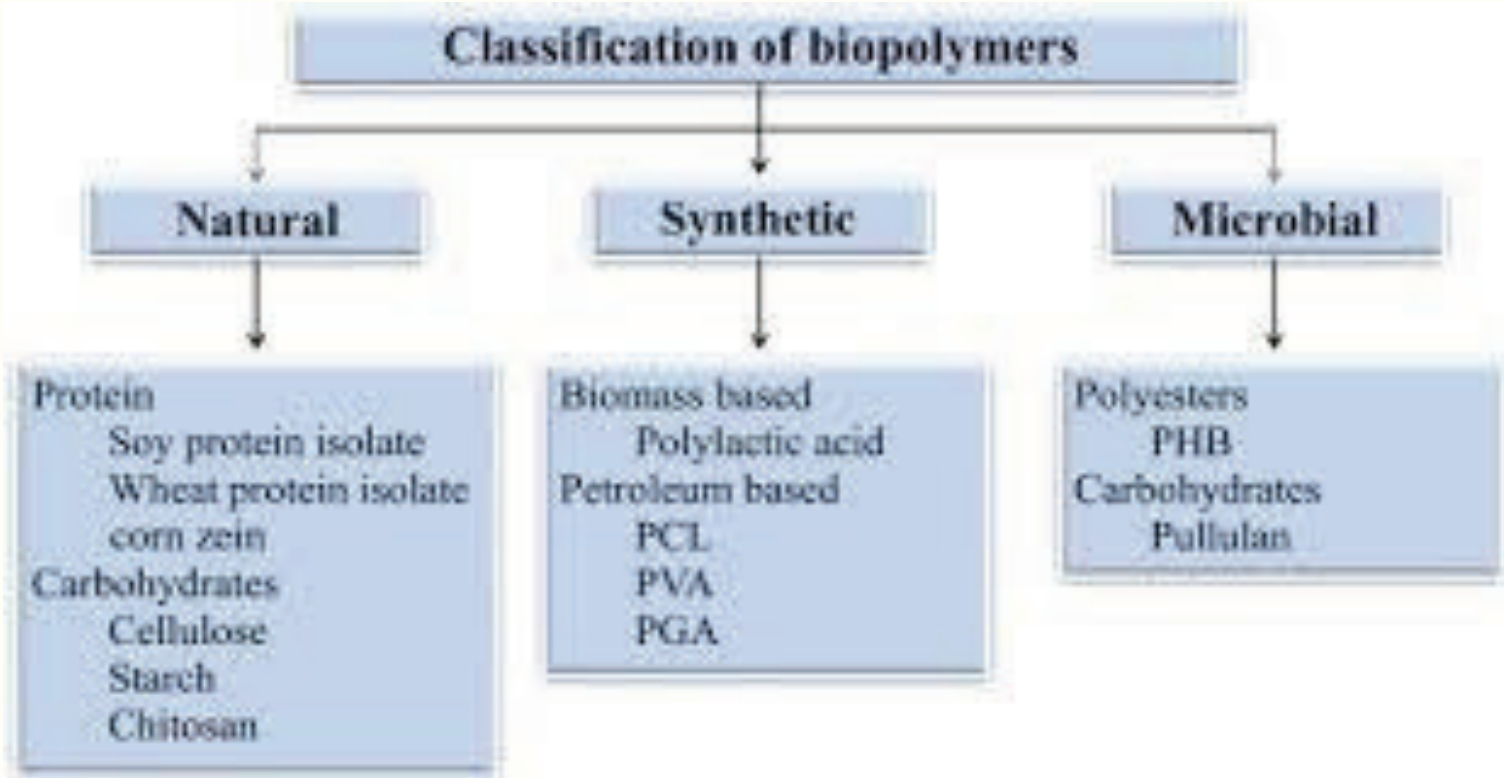
Key Role:

- ❖ As a fertilizer
- ❖ As a Food Additive
- ❖ As an Emulsifying Agent
- ❖ As a Surgical Thread



Ref: as open material

Classification Biopolymers



Ref: Wimmer *et al* Food Packaging, 2017, Pages 79-110

Composite And their Processing

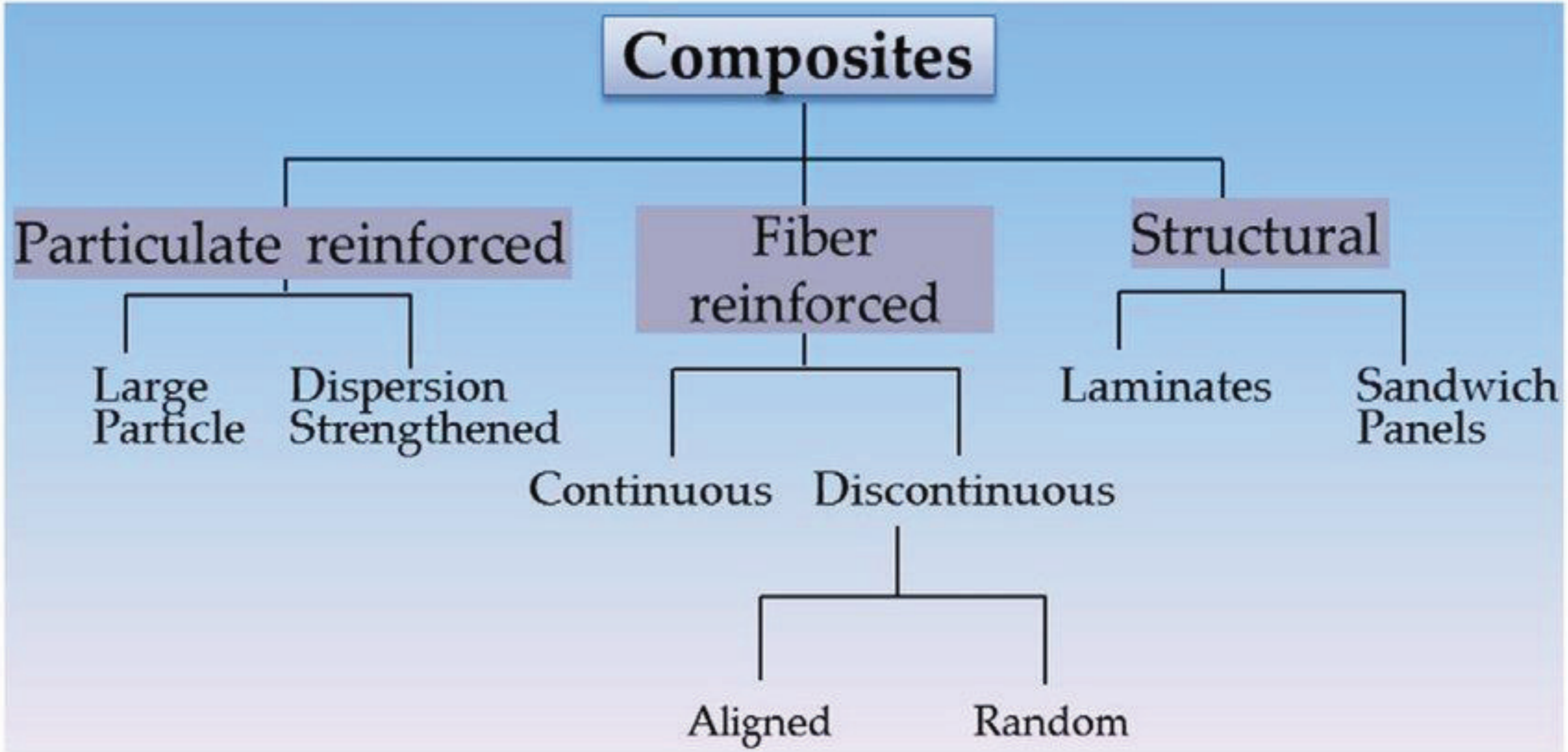
A composite material is a combination of two materials with different physical and chemical properties. When they are combined, they create a material which is specialized to do a certain job, for instance to become stronger, lighter or resistant to electricity. They can also improve strength and stiffness. The reason for their use over traditional materials is because they improve the properties of their base materials and are applicable in many situations(WHAT IS A COMPOSITE MATERIAL?)

WHAT ARE THE DIFFERENT TYPES of COMPOSITES?

a) Ceramic matrix composite
b) Metal matrix composite
c) Reinforced concrete
d) Glass fiber reinforced concrete
e) Engineered wood
f) Fiberglass

Ref: https://www.twi-global.com/

Classification of Composites



Ref: Paul, R. & Dai, Liming. (2018). Interfacial aspects of carbon composites. Composite Interfaces. 10.1080/09276440.20

Classification of Composites

Composites have excellent characteristics :

- ❖ High, directional strength (anisotropy) makes structures and properties possible that cannot be achieved with conventional materials
- ❖ With fiber composites, rigidity can be calculated and modified with the utmost precision from elastic to maximum rigidity
- ❖ Fiber-reinforced plastics are much lighter than metals yet can still achieve their rigidity Extremely high resistance to corrosion gives a long service life in even the most aggressive environments. Ideal for industry applications
- ❖ Composites and their surfaces are very stylish: they look good and offer varied design options, including new designs.

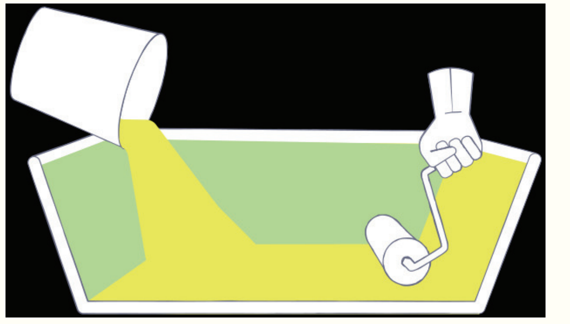
Ref: https://www.connova.com/en/solutions/composite-components/composite-advantages/

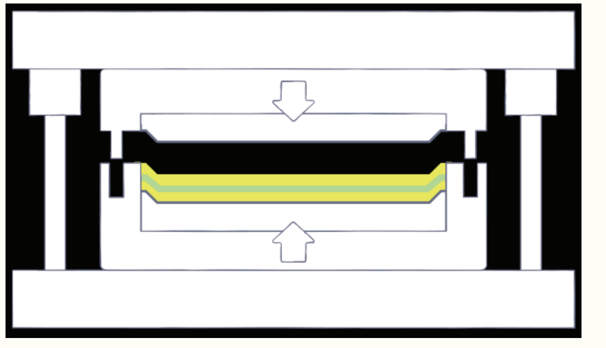
Processing of Composites

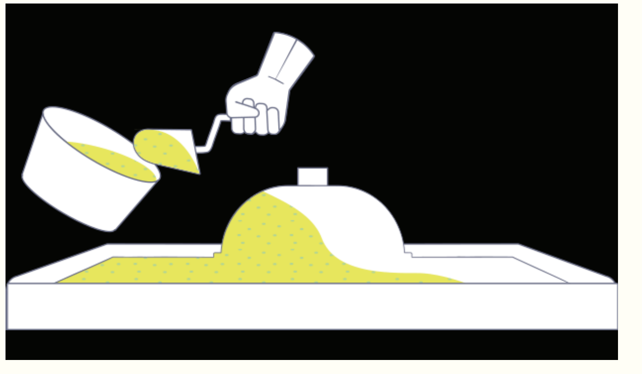
There are three types of composite manufacturing processes:

- Open molding
- Closed molding
- Cast polymer molding

Ref: Composite Lab







Application of Composites

Composites are used in a wide variety of markets, including

- ❖ Aerospace
- ❖ Architecture
- ❖ Automotive
- ❖ Energy
- ❖ Infrastructure
- ❖ Marine
- ❖ Military
- ❖ Sports and recreation.

Ref: http://compositeslab.com/where-are-composites-used/

ADDITIVE in POLYMER

Polymer additives are the chemicals that are added to polymer matrix to improve the process-ability of polymers, enhance the service life of the polymer product or to suit some special end use requirement of the product (What are Polymer additives?).

Analogy:

For example, To make a cake we need flour (Matrix) and several additives like egg(stiffening agent), sugar (taste enhancer), butter (mold release agent), baking soda (blowing agent), vanilla (odor additive)

Ref: https://www.quora.com/What-are-polymer-additives

TYPE OF POLYMER ADDITIVE

The most common polymer additives are:

- ❖ Stabilizers
- ❖ Plasticizers
- ❖ Lubricants
- ❖ flame retardants

Stabilizers are added to prolong the useful life of a polymer formulation by protecting it from thermal and light-assisted oxidation. Stabilizers are divided into four main classes:

1. UV absorbers (Benzophenones & Triazoles)
2. Primary antioxidants (Phenols)
3. Secondary antioxidants and quenchers (Hydroperoxide & Organonikel)

Lubricants are added to make the polymer easier to process. Lubricants are typically fatty alcohols, acids and esters and hydrocarbon waxes

Plasticizers (softeners) are low-molecular-weight polymers that increase the spacing between chains of crystalline polymer to make them more flexible and, thereby, tougher.

Ref: T.P. Hunt, in Encyclopedia of Separation Science, 2000
ALLEN D. GODWIN, in Applied Polymer Science: 21st Century, 2000

TYPE OF POLYMER ADDITIVE

They also reduced polymer glass transition temperature. The polymer is consequently less brittle and more easily worked. Typical plasticizers are phthalates, adipates and polychlorinated hydrocarbons. Flame retardants are typically chlorinated organophosphates.

Ref: T.P. Hunt, in Encyclopedia of Separation Science, 2000
ALLEN D. GODWIN, in Applied Polymer Science: 21st Century, 2000

ADVANTAGE OF POLYMER ADDITIVE

Few advantage of Polymer Additives as follows:

- Improved Processing
- Decreased Material Costs
- Extended Life Span
- Reduced Flammability
- Improved Flexibility

Ref: https://amcorplastics.com/blog/top-5-benefits-of-polymer-additives/#

HIGH PERFORMANCE POLYMER

What are high performance polymers?

High performance polymer (glassy polymer) is a group of polymer materials that are known to retain its desirable mechanical, thermal, and chemical properties when subjected to harsh environment such as high temperature, high pressure, and corrosive chemicals.

Examples:

- Fluoropolymers
- Phenolic resins
- Epoxy resin
- hetero-cyclic polymers, and inorganic polymers

Ref: Reactive and Functional Polymers, 2016

Classification of HPPs

Classification of high-performance polymers (compounds):

1. Hardwearing.
2. high temperature resistant
3. high mechanical strength

High Performance polymers have a thermal resistance >150°C. Examples of hard-wearing high-performance polymers are:

- ❖ Polyetheretherketon (PEEK)
- ❖ Polyethersulfon (PS)
- ❖ Polyimide (PI)

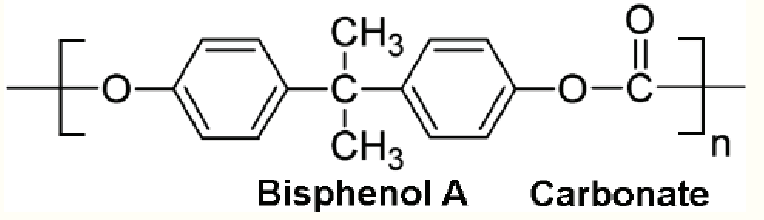
Most high-performance polymers (compounds) are reinforced by fibers or/and filled with internal anti friction lubricants.

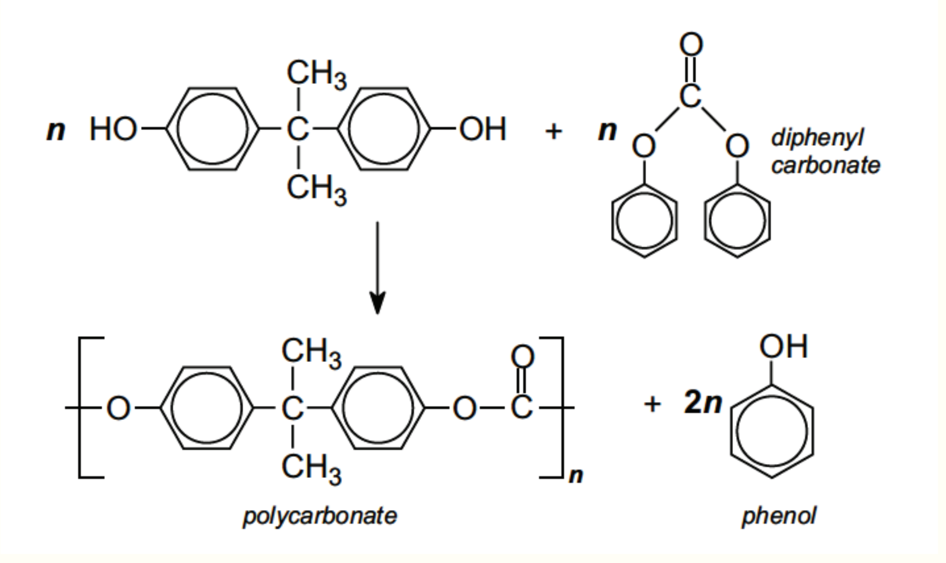
Ref: Reactive and Functional Polymers, 2016

Preparation, Properties and Application of HPPs

POLYCARBONATE(PC):

Polycarbonate is most formed with the reaction of bis-phenol A (produced through the condensation of phenol with acetone under acidic conditions) with diphenoxymethylene derivatives in an interfacial process. PC falls into the polyester family of plastics.



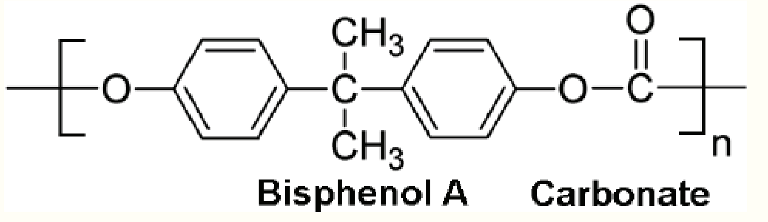


Ref:
https://www.essentialchemicalindustry.org/polymers/polycarbonates.html

Preparation, Properties and Application of HPPs

POLYCARBONATE(PC):

- Polycarbonates are strong, stiff, hard, tough, transparent engineering thermoplastics that can maintain rigidity up to 140°C and toughness down to -20°C
- Transparency, excellent toughness, thermal stability and a very good dimensional stability make Polycarbonate (PC) one of the most widely used engineering thermoplastics
- Tensile Strength 70 - 80 N/mm² Notched Impact Strength 60 - 80 Kj/m² Thermal Coefficient of expansion 65 x 10-6 Max Cont Use Temp 125 °C Density 1.20 g/cm3

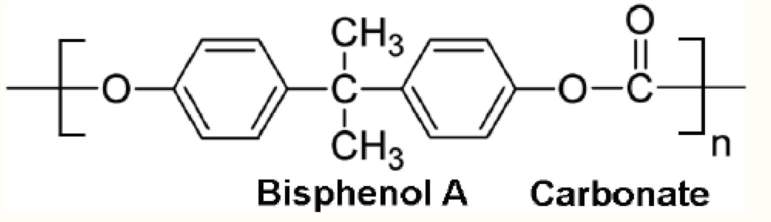


1. Ref: https://www.essentialchemicalindustry.org/polymers/polycarbonates.html
2. https://www.bpf.co.uk/plastipedia/polymers/polycarbonate.aspx

Preparation, Properties and Application of HPPs

POLYCARBONATE(PC):

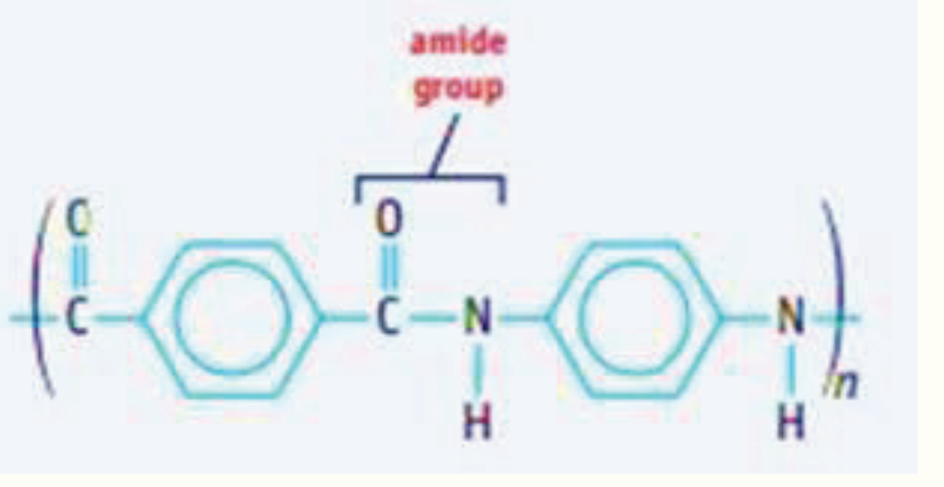
PC finds usage in a host of markets, notably in the automotive, glazing, electronic, business machine, optical media, medical, lighting and appliance markets.



1. Ref: https://www.essentialchemicalindustry.org/polymers/polycarbonates.html
2. https://www.bpf.co.uk/plastipedia/polymers/polycarbonate.aspx

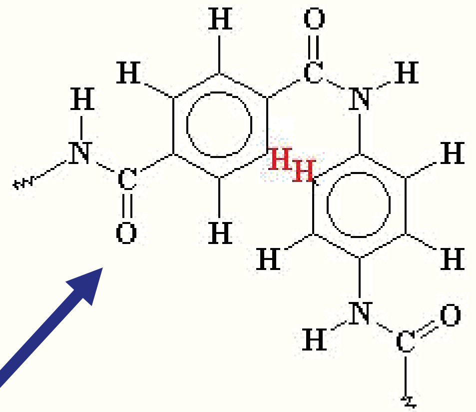
KEVLAR

Kevlar is made by a condensation polymerization of an amine (para-phenylene diamine) and acid chloride. The resultant aromatic polyamide contains aromatic and amide groups which makes them rigid rod like polymers and is more properly known as a para-aramid. The aramid ring gives Kevlar thermal stability. The para-structure makes it strong and increases the modulus.

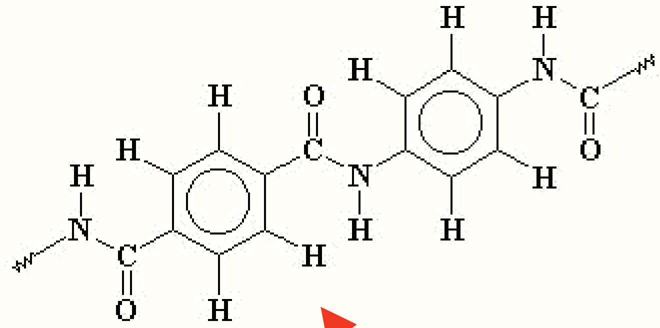


Ref: Paul May, University of Bristol. 2016
http://www.chm.bris.ac.uk/webprojects2002/edwards/chemistry.htm

KEVLAR



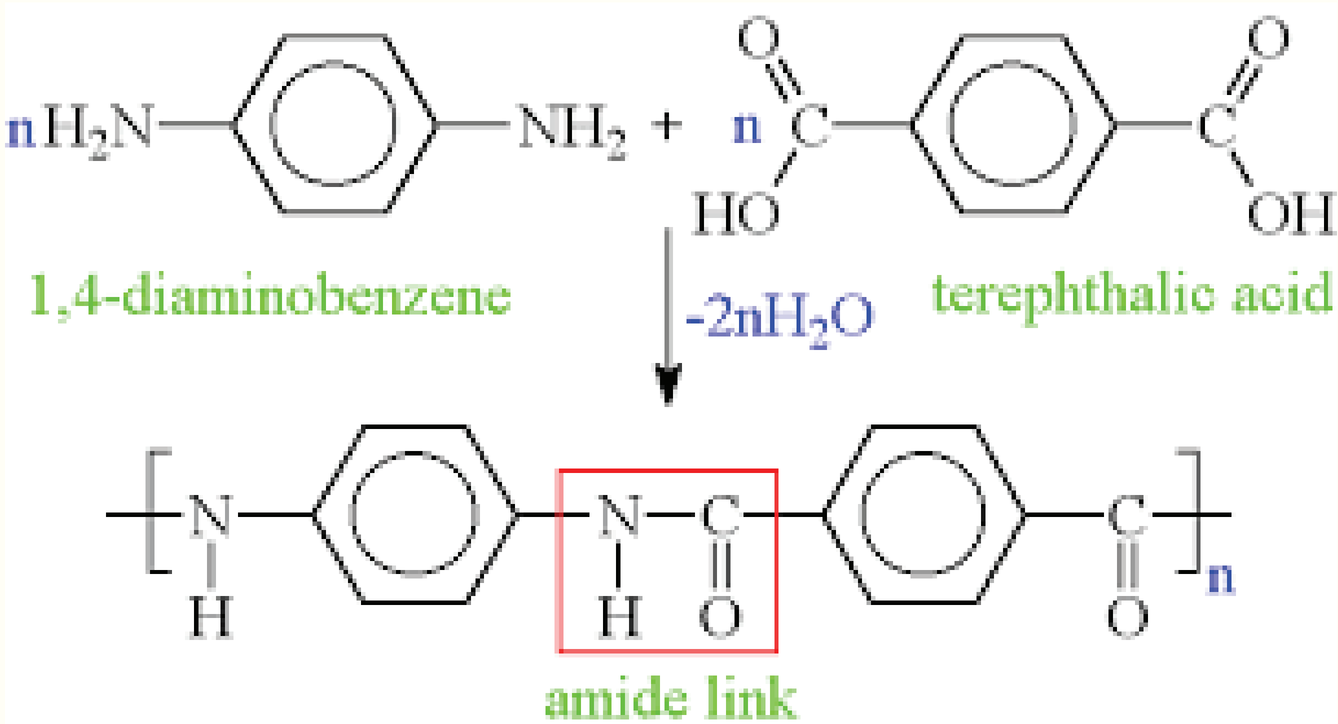
The hydrogens are too close together in the *cis* conformation



In the *trans* conformation there is much more room, and so less hindrance.

Ref: Paul May, University of Bristol. 2016
http://www.chm.bris.ac.uk/webprojects2002/edwards/chemistry.htm

KEVLAR



Ref: Paul May, University of Bristol. 2016
http://www.chm.bris.ac.uk/webprojects2002/edwards/chemistry.htm

KEVLAR

Properties & Application

Kevlar has unique properties, such as high tensile strength, high toughness, and chemical stability at high temperatures in aromatic polyamides. Kevlar is widely-used as a friction material in the automotive industry and a combustion protection material in the aerospace industry.

Ref: Paul May, University of Bristol. 2016
http://www.chm.bris.ac.uk/webprojects2002/edwards/chemistry.htm
https://doi.org/10.1016/B978-0-08-100904-8.00002-X

KEVLAR

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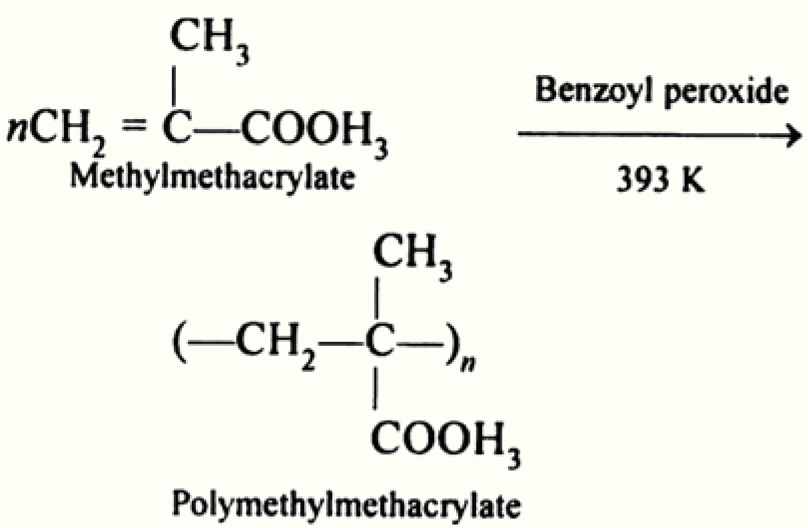
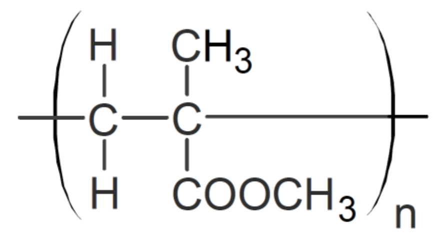
PMMA

Polymethyl methacrylate (PMMA), a synthetic resin produced from the Free radical polymerization of methyl methacrylate yielding atactic polymers. A transparent and rigid plastic, PMMA is often used as a substitute for glass in products such as shatterproof windows, skylights, illuminated signs, and aircraft canopies. It is sold under the trademarks Plexiglas, Lucite, and Perspex.



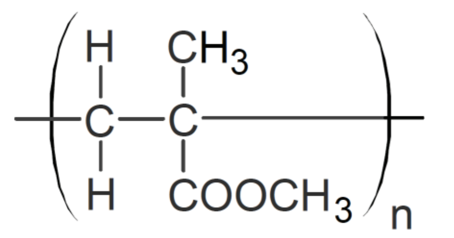


Polymethyl methacrylate: PMMA

Ref: https://www.britannica.com/science/polymethyl-methacrylate
http://polymerdatabase.com/Polymer%20Brands/PMMA.html

PMMA

- PMMA is known for its stiffness, hardness and excellent weatherability
- Most commercial grades of PMMA, however, are atactic with a glass transition temperature of 398 K (125 °C)
- High volume amorphous, transparent and colorless commodity thermoplastic that can be easily processed and converted into many finished and semi-finished products
- Because of its high transparency (92% transmission) PMMA can be used as a lightweight and shatter-resistant replacement for regular glass



Polymethyl methacrylate: PMMA

Ref: https://www.britannica.com/science/polymethyl-methacrylate
http://polymerdatabase.com/Polymer%20Brands/PMMA.html
https://www.zigya.com/

Thank You For Reading

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