Condensation polymers

Condensation polymerisation usually requires two different molecules that can react together to form a bond such as an ester or amide bond with the elimination of a small molecule such as water.

Examples include synthetic polymers such as polyesters and polyamides as well as peptides and proteins.

Polyester (example 1 : Terylene)

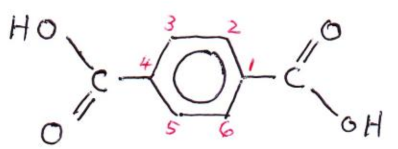
Polyester is widely used to make a variety of items from drink bottles to clothing and carpeting.

It is made by polymerising ethane-1,2-diol with 1,4-benzenedicarboxylic acid (terephthalic acid) with the elimination of water.

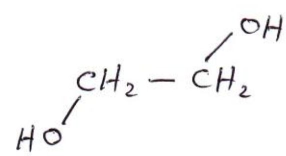
The product is known as Terylene.

The 1,4 links in this polymer produce a linear polymer that is suitable for spinning into fibres.

The two monomers are:

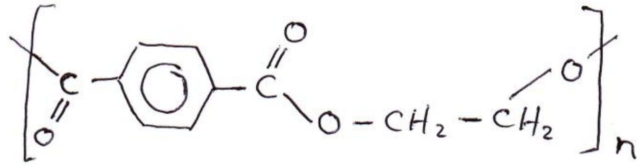


1,4-dicarboxylic acid



ethane-1,2-diol

One repeating unit of the polyester chain:



Example 2: Poly(lactic acid), PLA

This polymer is becoming increasingly popular because the starting material used to produce it comes from plant starch, not from chemicals made from dwindling supplies of crude oil.

Crops such as corn, wheat, beer and potatoes can all be used as raw materials.

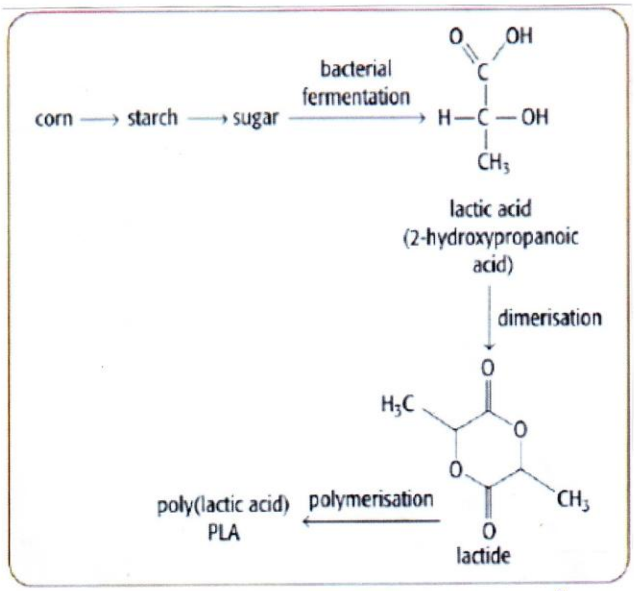
PLA also has other advantages, such as its biodegradability.

It has also been shown that the life cycle of PLA, starting from the crop and ending at scrapping, reduces greenhouse gas emissions by around 30–50% compared with the manufature and use of traditional oil-based plastics.

The polymerisation of lactic acid (systematic name: 2-hydroxypropanoic acid) produces PLA.

In industry, the more reactive lactide derivative is used to make PLA.

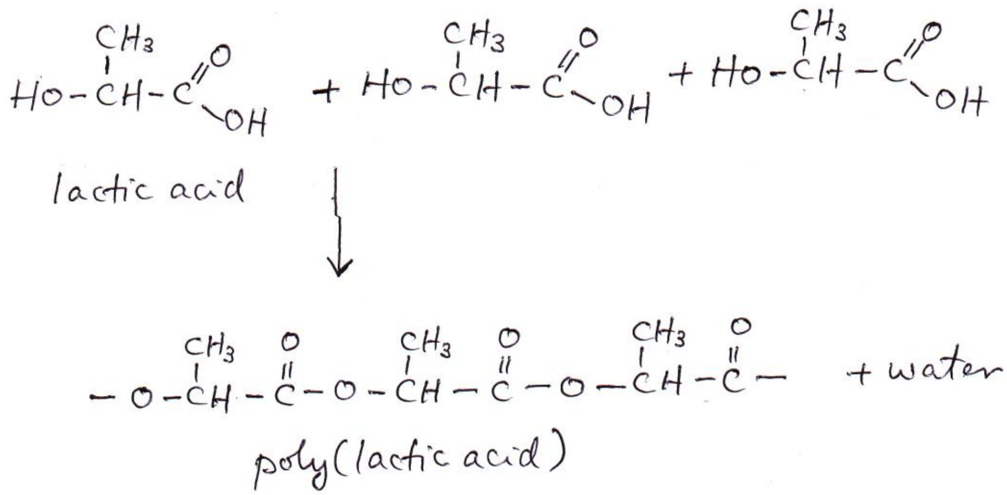
The lactic acid molecules can undergo esterification (a condensation reaction), forming water as well as the polymer.



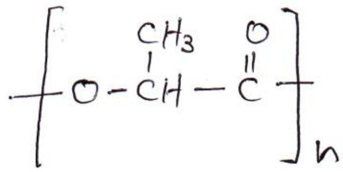
The production of poly(lactic acid), PLA.

The lactic acid (2-hydroxypropanoic acid) molecule has an alcohol and a carboxylic acid group within each molecule.

The molecules can react to form ester links between each other:



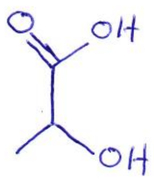
The repeating unit in the PLA polymer as:



Exercise 1

Draw the skeletal formula of 2-hydroxypropanoic acid (lactic acid).

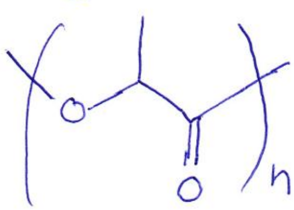
Workings



Exercise 2

Draw the repeating unit of PLA in skeletal form.

Workings



Polyamide

Example 1 : Spider Silk

Based on weight, spider silk is five times stronger than steel of the same diameter.

Spider silk is a protein that is in the same group of proteins as hair, nails and ligaments.

The spider can spin different types of silk for different functions.

The line it spins when moving down from a high place is the strongest.

It is made from a protein called fibroin.

Fibroin has a molecular mass of 200 000–300 000 and consists of 42% glycine and 25% alanine, with the remainder coming from seven other amino acids.

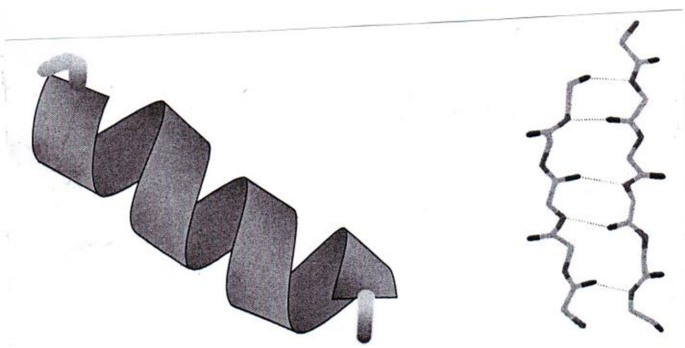
The alanine molecules occur in polyalanine regions, where between four and nine alanine molecules are linked in a block.

The elasticity of spider silk comes from regions that are rich in glycine.

In these regions a sequence of five amino acids is repeated.

After each sequence a 180° turn occurs producing a spiral.

Ordinary silk produced by silk moths has a β-pleated sheet structure, held together by hydrogen bonds.



The spiral structure of spider silk and the β-pleated sheet structure of ordinary silk.

The most elastic spider silk is capture silk that has about 43 repeats of the 5-glycine fragment and can extend to 200% of its length.

Dragline silk with only about 9 repeats can only extend by about 30% of its length.

The strength of the spider silk arises from the hydrogen bonds between its polymer chains

Example 2: Kevlar®

Kevlar is a synthetic polyamide with strong intermolecular forces.

The strength of Kevlar reflects the strength of one of nature's strongest fibres, the silk spiders use to make webs.

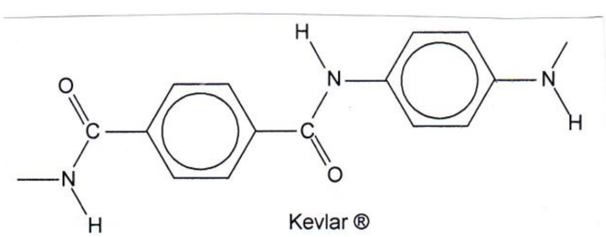
Based on weight, Kevlar fibres can be nine times as strong as steel.

Kevlar is used for bullet-proof vest and also in racing leathers for motorbike riders.

Reinforcing Kevlar with spider silk would make these vests even stronger.

Kevlar has replaced steel in rubber tyres, with the weight reduction leading to a small reduction in fuel consumption.

One repeat unit of Kevlar:

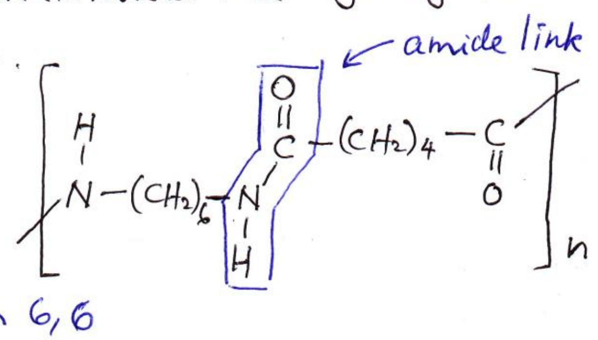


Kevlar ®

Kevlar polymer chains are linear, with a high degree of alignment between chains.
This is possible because the polymer chains are not brached with side-chains.
If side-chains are present it is more difficult for the polymers to line up, resulting in weaker intermoleculor forces.

Example 3: Nylon

Nylon was first made by reacting a dicarboxylic acid with a diamine.
This condensation reaction, releasing water molecules, is similar to the polymerisation of the amino acid units in natural silk.
Silk and nylon are strong materials because of the extensive hydrogen bonding between amide links.
Nylon is cold drawn to align the polymer chains, which maximises the hydrogen bonding between chains.

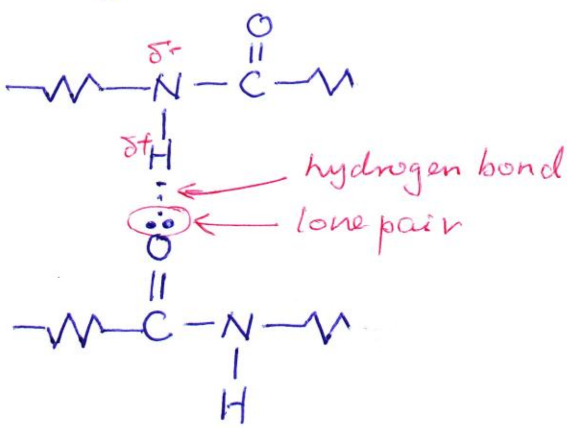


Nylon 6,6

Exercise 3

Draw a diagram to show a hydrogen bond between two amide links on neighbouring polyamide chains

Workings



Exercise 4

Identify one difference between the monomers that make up a nylon and that form a protein.

Workings

In nylon, the two amine groups and the two carboxylic acid (or acyl chloride) groups are usually separated by several carbon atoms within each monomer molecule.

In the natural amino acids that form proteins, the amine group and the carboxylic acid group are always seperated by one carbon atom.

In nylon, the amine and carboxylic acid (or acyl chloride) groups are in different monomer molecules whereas in proteins the amino acids have both functional groups in the same molecule.

(Note: some nylons made from a single monomer molecule which has both functional groups, eg. $HOOC(CH_2)_5NH_2$)

Natural polymer

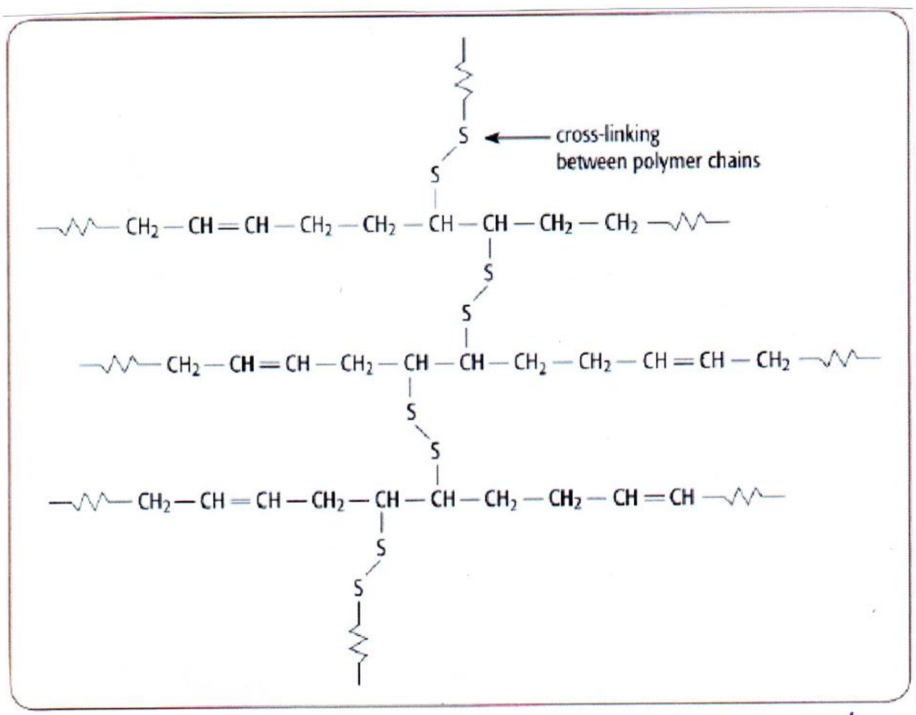
Example : rubber

The monomer of natural rubber is 2-methyl-1,3-butadiene.

The intermolecular forces between natural rubber polymers are van der Waals' forces.

A process called vulcanisation was invented to make rubber tyres more resilient and hardwearing.

This links rubber polymer chains by covalent bonds across 'sulfur brides'.



The sulfur bridges between polymer chains make rubber more resilient.

Exercise 5

The word 'resilient' means to return to the original form or position after being bent, compressed or stretched.
Explain why the process of vulcanisation makes rubber 'more resilient'.

Workings

The cross-linking sulfur atoms form strong covalent bonds between the flexible polymer chains ensuring they return to their original positions following distortion.

Exercise 6

Give an equation to show the polymerisation of 2-methyl-1,3-butadiene to form rubber.

Workings