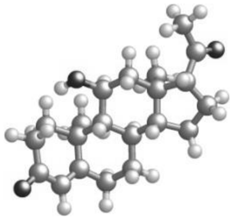

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Synthetic Polymers

A Historical Perspective – The Life of Wallace Carothers

By the early 20th Century, the demand for natural fibres had begun to outstrip their supply. Science turned to the idea of creating artificial (synthetic) fibres to reduce the pressure on these plant and animal herds. The three most successful of these synthetic fabrics – nylon, rayon and polyester – have accounted for almost 20% of total clothing sales over the past 30 years. If not for these synthetic fabrics, cotton and wool would probably be five to ten times more expensive than they are today.

Charles Goodyear's vulcanised rubber (1839) counts as the first synthetic clothing material, because raw rubber had to be mixed with chemical additives (sulphur, magnesium and calcium oxide) and then heated in a furnace.

Throughout the second-half of the nineteenth century, silk was a popular and fashionable material. However, limited supplies meant that silk was also expensive. Consequently, researchers in America and Europe sought ways to create "artificial silk."

British researchers C. F. Cross and E. J. Bevan and French scientist Louis de Chardonnet independently developed the same idea for "artificial silk." They washed a wood pulp (cellulose) fibre in sodium hydroxide and treated it with carbon disulphide (CS_2) to create a substance called xanthate. Xanthate could be liquefied and then forced at high pressure through tiny spinneret holes to produce long, fine fibres. For twenty years, this fibre was simply called "artificial silk." In 1924, a British manufacturing company, Courtaulds, renamed the fibre *rayon*.

Life was never easy for Wallace Carothers, but the story of how he invented nylon is a tragedy of Shakespearean proportions. Shy, withdrawn and uncomfortable with people, Carothers enrolled at a Missouri college in 1915 to become a teacher. After graduating, he took up a teaching position, but developed a facial tick and insomnia from the stress of teaching. Unable to continue, he retreated to university to study for his doctorate in chemistry.

In 1928, the Dupont Company offered Carothers a chance to lead an experimental research team at its Wilmington, Delaware, facility. The company gave him a lab, a budget and support staff and told him to create new synthetic fibres and materials.

Carothers decided to start his search for a new synthetic silk by using recent research into the structure of rubber. Other researchers had discovered that vulcanised rubber was made up of long chains of molecules called polymers. So Carothers built long carbon chain polymers in his lab. Then he and his team did everything that they could think of to these polymers to see what would happen and what they could produce. They added them to acids and to alkalis. They added copper, magnesium and every other metal and alloy that they could think of. They heated them and they froze them.

Carothers grew disillusioned and decided to search elsewhere. He issued an order to stop this line of research just as his team was conducting a new experiment in which they mixed hydrochloric acid with compounds similar to ethenyl ethanoate derived from the original polymers. This combination produced a spongy, elastic material – interesting, but certainly not a suitable replacement for silk. Consequently, Carothers decided not to pursue this line of research any further. However, other chemists at DuPont recognised the potential of this new elastic compound and performed further research into it. DuPont liked the new material and marketed it under the name *neoprene*.

The success of this product that he had created, but had failed to recognise the importance of, haunted Carothers. He withdrew more and more into his lab and further away from people.

In spring 1933, Carothers turned his attention to heavier, longer polymer chain molecules. Once again, the research team produced thousands of different compounds which had to be tested. Virtually all of them proved to be worthless. One of the compounds, however, did get Carothers's attention. It looked like silk and was at least as strong as silk. However, it could not be spun into fine thread-like fibres because it melted too easily, and heat was required for the spinning process. Again, he set the compound aside.

In early 1935, Julian Hill, one of Carothers's team members began work on polyesters. That spring, he developed a new way of pulling strands of polyester from a beaker full of chemical reagents. His method did not require heat and was called "*cold-drawing*."

Carothers took no notice. Another team member suggested that they should try cold drawing on the silk-like compound that they had produced in 1933, but Carothers was not interested. Other members of his research team decided to try it, and found that it worked.

DuPont named the new substance *nylon* and was thrilled by its look, feel and strength. After another 18 months of testing, the company filed for a patent and began to market nylon in 1939.

It is a great pity that Carothers did not live to see his brilliant discovery become the wonder of the 1940s and 1950s. Neither did he survive to see nylon go on to be the most successful synthetic fibre ever made. Plagued by a life of clinical depression, troubled by his failure to follow-up on his discoveries and distress by the death of his sister, Wallace Carothers committed suicide by ingesting potassium cyanide in April 1937.

In 1951, James T. Dickson and John R. Whinfield – working in London under contract from DuPont – used Carothers's experimental methods to invent *Dacron*. In the late 1940s, various researchers invented a range of other synthetic polymers, including *Orlon* and *Acrilon*.

In 1938 Roy Plunkett, working in a DuPont research lab, discovered the addition polymer poly(tetrafluoroethene). DuPont marketed poly(tetrafluoroethene) under the trade name *Teflon*. In 1956, an electrical engineer by the name of Bill Gore investigated *Teflon* as an improved insulation for electrical wiring. A little over a decade later (1969) Bill Gore's son, chemist Bob Gore, discovered that *Teflon* fibres could be drawn into a porous, flexible material, which is now marketed under the trade name *Gortex*.

Reference:

Haven, K. F. (2005). 100 Greatest Science Inventions of All Time. Westport, CT: Libraries Unlimited.
ISBN: 1-59158-264-4

Questions

Question One:

Which *Habits of Mind* were demonstrated by Wallace Carothers and his research team during their discovery of the different polymers?

Question Two:

To what extent can the work done by Wallace Crothers and his research team be considered as *interdisciplinary* or *multidisciplinary*? Which *macroconcept(s)* best describe the research that they did? Justify your answers.

Question Three:

Give the full structural formula for the ester ethenyl ethanoate, the precursor used to make the monomer for the synthesis of neoprene.

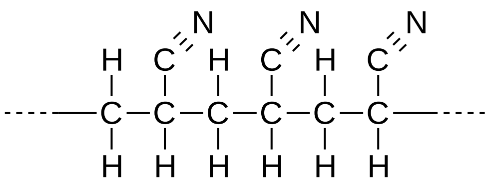
Question Four:

a) Neoprene is made from the monomer 2-chlorobuta-1,3-diene. Give the full structural formula of 2-chlorobuta-1,3-diene.

b) Give the full structural formula of neoprene (*i.e.* the addition polymer that is formed from 2-chlorobuta-1,3-diene) showing at least three repeating units.

Question Five:

The structural formula of the addition polymer *Orlon* is given below. Give the full structural formula and name of the monomer that is used to synthesise *Orlon*.

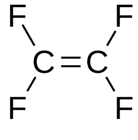


Orlon

poly(prop-2-enenitrile)

Question Six:

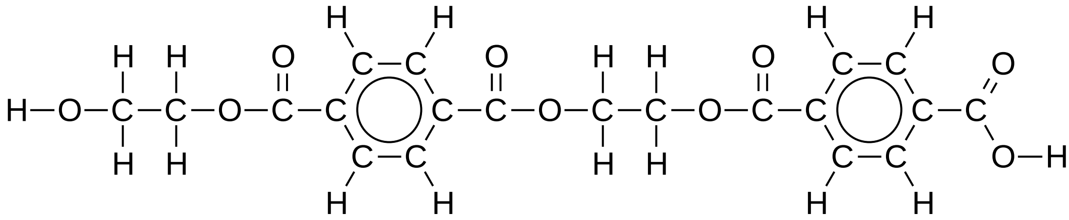
The structural formula of the monomer that is used to synthesise *Teflon* is given below. Give the full structural formula of the polymer *Teflon* showing at least three repeating units.



tetrafluoroethene

Question Seven:

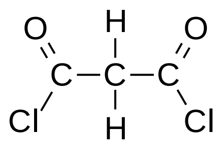
The structural formula of the condensation polymer *Dacron* is given below. Give the full structural formulae and names of the two monomers that are used to synthesise *Dacron*.



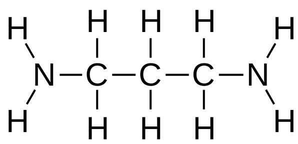
Dacron

Question Eight:

a) The structural formulae of the two monomers that are used to synthesise *nylon 3,3* are given below. Give the full structural formula of the condensation polymer *nylon 3,3* showing at least four repeating units.



propanedioyl dichloride



propane-1,3-diamine

b) Which simple covalent compound is produced as a side-product of this condensation reaction?

c) Which intermolecular forces of attraction do you expect to exist between two chains of nylon 3,3? Illustrate your answer with a clear diagram.

Answers

Question One:

For guidance – the sixteen *Habits of Mind*:

1. Persisting
2. Thinking and Communicating with Clarity and Precision
3. Managing Impulsivity
4. Gathering Data Through All Senses
5. Listening with Understanding and Empathy
6. Creating, Imagining and Innovating
7. Thinking Flexibly
8. Responding with Wonderment and Awe
9. Thinking About Thinking (Metacognition)
10. Taking Responsible Risks
11. Striving for Accuracy and Precision
12. Finding Humour
13. Questioning and Posing Problems
14. Thinking Interdependently
15. Applying Past Knowledge to New Situations
16. Remaining Open to Continuous Learning

Question Two:

For guidance – generalisations about *macroconcepts*:

Change:

- Change generates more change.
- Some changes are reversible.
- Change occurs amidst continuities.
- Change can be steady, cyclic, random or chaotic.
- Change is inevitable in all systems.
- Change is not always equal to progress, *i.e.* change can be positive or negative.
- Change is linked to time.
- Change can be a consequence of spontaneous and/or planned events.
- Some changes can be measured, analysed and predicted. Other changes cannot.

Systems:

- Systems have elements that interact with each other to perform a function.
- Systems are composed of subsystems.
- Systems may be influenced by other systems.
- Systems interact.
- Systems follow rules.

<u>Models:</u>

• Models simulate real world processes.

• Models facilitate testing and prediction.

• Models can be physical, conceptual or mathematical.

• Models simplify processes or behaviours in the real world.

• Models involve variables.

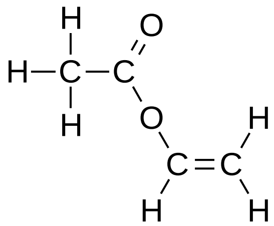
<u>Scale:</u>

• Scale involves measurable properties.

• Scale is a ratio and it involves a range of magnitudes.

• Scale enables data of extreme magnitudes to be managed with ease.

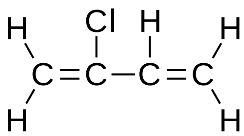
Question Three:



ethenyl ethanoate

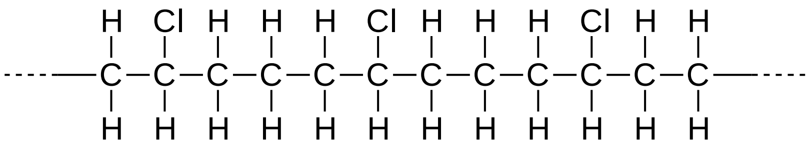
Question Four:

a)



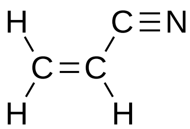
2-chlorobuta-1,3-diene

b)



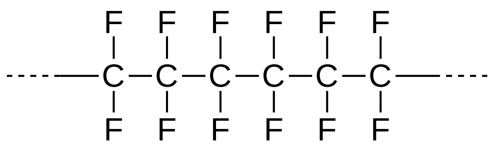
poly(2-chlorobuta-1,3-diene)

Question Five:



prop-2-enenitrile

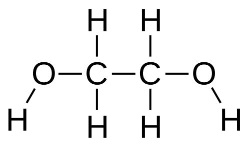
Question Six:



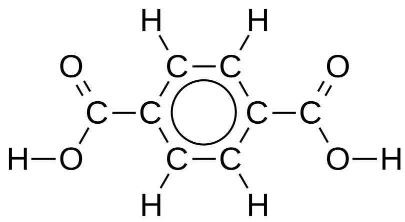
Teflon

poly(tetrafluoroethene)

Question Seven:



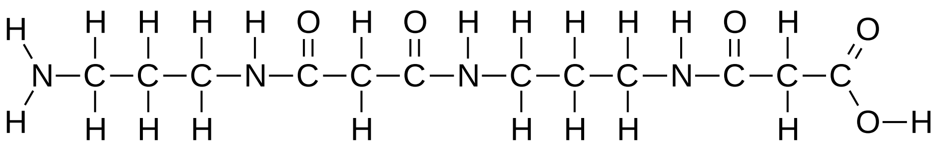
ethane-1,2-diol



benzene-1,4-dicarboxylic acic

Question Eight:

a)



nylon 3,3

b) Hydrogen chloride.

c)