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Nylon: The Natural Synthetic

War is always terrible, whether a country wins or loses. However, the technological advances that arise because of the demands of war are often forgotten. During wars, countries become strapped for crucial resources and scientists are called upon to relieve the strain.

The emergence of nylon is a direct product of World War II. Initially, nylon was an inexpensive alternative to silk that was used mainly in women's clothing. However, immediately after the start of the U.S.-Japan War, nylon became important for war-related applications. Following the end of that war, Nylon's impact on the world was not only measured by its direct uses, but also by the doors it opened for production of other synthetic materials.

Although man-made silk was not obtained until the early 1900s, people longed for a silk alternative for centuries. In 1665, microscopist Robert Hooke, famous for his law of elasticity, dreamed in the *Micrograhia* of a way to make an artificial silk that may perhaps be better than silk. During the early 1900s, German chemists were at the forefront of polymer studies; most notable was Hermann Staudinger who published a major work on polymerization in 1920. However, at that time, the exchange of scientific ideas was limited and opposing views arose. Many scientists at the time scoffed at the idea of long-chain molecules; they believed that materials such as rubber and silk were assemblies of small molecules held together by "partial valences." Staudinger was the sole defender of the macromolecule idea in Germany. In the late 1920s, an American chemist began research that would affect not only the scientific community, but the entire world.

In 1927, The Du Pont company opened a research facility in Wilmington, Delaware; its Chemical Director Charles Stine chose Wallace Hume Carothers as its lead researcher. In his laboratory, dedicated to pure science, dubbed "Purity Hall," Carothers began his attempts to synthesize macromolecules using simple, well-known organic reactions with small molecules. Emil Fischer, the Nobel Prize winner of 1902, had made a macromolecule with a molecular weight of 4021; Carothers did not want to merely beat this number, but far exceed it. During his research, Carothers created a strong foundation for modern polymer chemistry with his paper "Polymerization," but until 1930, a polymer superior to Fischer's evaded Carothers' research team.

With the help of a distillation device known as a molecular still, in April 1930 Carothers' co-worker Julian Hill was able to construct a polymer with a molecular weight greater than 10,000. Twelve days later, the polymer was drawn out into fibers that exhibited properties similar to those of cellulose and silk. The polymer's tensile strength, pliability, elastic recovery, transparency, luster, and its chemical structure resembled those of natural fibers. The *New York Times* declared "Chemists Produce Synthetic 'Silk'". This polymer, however, had no commercial use because it could not stand up to solvents or heat. As far as Carothers was concerned, he had found a superior polymer and his research objectives were met. However, Du Pont was interested in research that could be brought to market. Newly appointed Chemical Director Elmer Bolton pushed for a practical fiber.

In February 1935, after many failures, a polymer was finally ready for manufacture. It was initially synthesized by Gerard Jean Barchet . It melted at 263 ˚C and was stronger and more elastic than any natural fiber. Most important, its two raw materials could be produced from benzene, available from abundant coal. Wallace Carothers had devoted his entire life to the construction of such a super polymer, and although commercial applications were of no concern to him, this material was the turning point in the synthetic material revolution that was going to bring him fame. Tragically, Carothers had too many demons in his personal life and in April

1937, he took his own life with a cyanide pill. A year and a half later, a patent was issued under Carothers name and Charles Stine unveiled to the world the "first man-made organic textile fiber prepared entirely with raw materials from the mineral kingdom." Thus, nylon was born.

Nylon was first unveiled to the world at the World's Fair in New York City in 1939. Du Pont's groundbreaking material could "be fashioned into filaments as strong as steel, as fine as the spider's web, yet more elastic than any of the common natural fibers and possessing a beautiful luster." Although nylon was predated by synthetic fibers such as "PeCe Faser" and "Vinyon," it was unrivaled in its properties, applicability, and commercial output. In the public eye, the creation of a multifunctional material from everyday materials such as coal, water, and air bordered on miraculous. Carothers and his team were seen as modern day alchemists.

Nylon was first used commercially in 1938 in toothbrush bristles, but its real breakthrough was as a replacement for silk. Nylon was not as good as silk; it was better. The polymer was stronger than silk and this made a huge impact on women's clothing. At the time, sheer stockings were in style and nylon-based stockings were made nearly invisible. Demands for the latest stockings skyrocketed and production could barely keep up.

Nylon created a fashion craze, but its use in parachutes is what made it particularly useful during the war. Relations between the U.S. and Japan were deteriorating at the time, and the silk trade was in danger. Nylon provided an alternative to silk and was used in parachutes, ropes, tents, ponchos, and tires during the war. Before the war, nylon had virtually no influence on the fiber industry but by the end of WWII, nylon controlled 20% of the fiber market.

During the war, the public clamored for nylon but preference was given to war needs. When the war ended, Du Pont returned to producing nylon for commercial use and nylon boomed. The fashion world was crazy about this new material and began to use it in stockings, raincoats, windbreakers, and many other products. Nylon was followed by other polymeric products including polyesters, acrylics, and acetates. These materials took over much of fashion for the everyday person. Nylon was used to create a new age; it dominated fashion centers in Paris and Japan. Fashion and chemical technology had been merged as never before.

DuPont offers the definition: "Nylon is the generic name for all materials defined scientifically as synthetic fiber-forming polymeric amides having a protein like chemical structure; derivable from coal, air, and water, or other natural substances, characterized by extreme toughness and strength and by its peculiar ability to be formed into fibers and into various shapes such as bristles, sheets, etc." Nylon is functional because it is ductile and lightweight. Nylon's durability makes the production of strong, elastic materials possible.

Nylon is the product of a condensation reaction where two molecules bond together with release of H_2O. As shown in Figure 1, nylon was first formed in a condensation of hexamethylenediamine ($NH_2(CH_2)_6NH_2$) and adipic acid ($HOOC(CH_2)_4COOH$).

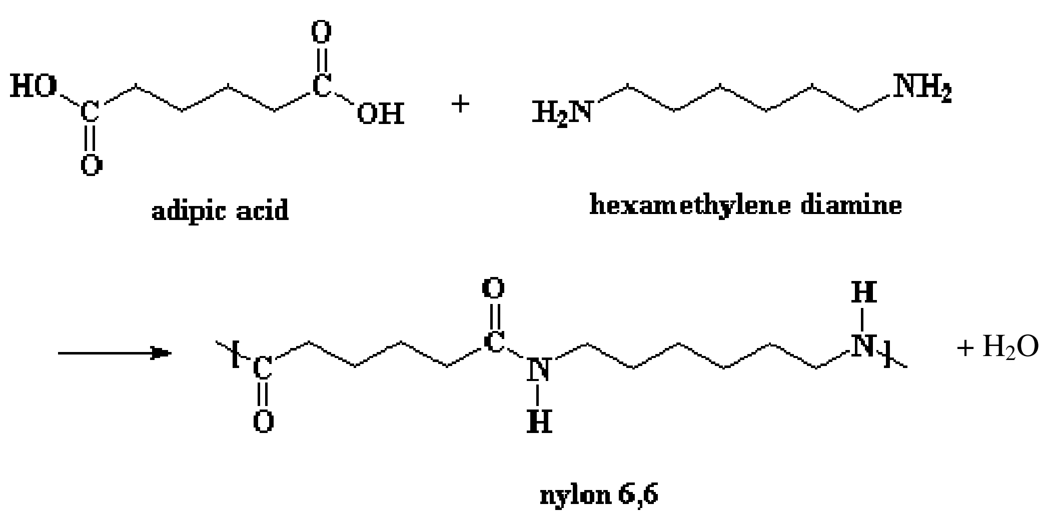

Figure 1-Synthesis of Nylon

Nylon's functionality is not only due to its macromolecular structure but also due to its physical history. A mechanical stress needs to be applied in a process known as cold-drawing for the fiber to be constructed. The discovery of this need for a mechanical stress was almost accidental. One of the names proposed for nylon (Fiber 66) was 'Duparooh', an acronym meaning 'Du Pont Pulls A Rabbit Out Of A Hat.'

Nylon has many uses. Nylon can be found in almost all types of clothing aside from stockings, from a bathing suit to snowboarding pants. Nylon dries very quickly and resists shrinkage or wrinkling when washed, making it ideal for athletic clothing such as windbreakers and shorts.

Nylon has a stake in fabrics outside of clothing as well; it can be found in carpets, musical strings, camping tents, and rope. In its solid form, nylon is used to make screws and gears for low-stress applications. Nylon can also be found in a variety of unrelated items such as tires, hair combs, and flak vests. It is even used in composite materials as a matrix for reinforcing fibers. Nylon provides a suitable material for a large variety of industries.

The major producer of nylon in the U.S. continues to be the Du Pont Corporation, followed by companies such as MTC, Allied, and American Enka. In 1982, 3,909 million pounds of nylon in its fiber form were produced along with 1,021 million pounds of solid nylon. Also in 1982, the cost to produce nylon 6,6 in solid form ranged from $760-1100 dollars/ thousand pounds. The fibrous form of nylon was more expensive to produce, coming in at $874-1420 dollars/thousand pounds.

When nylon began to replace silk, America took an important step in self-sufficiency. Prior to World War II, America not only relied on Japan for silk, but on Chile for nitrates for fertilizers and on Germany for pharmaceuticals. The creation of man-made silk showed that

America did not need to rely on foreign imports to satisfy its needs. Citizens on a widespread level began to believe that anything natural could be equaled, or even excelled, by a synthetic material. This belief spread throughout the entire world and motivated scientists and entrepreneurs to search for new man-made materials.

Nylon's use has diminished since its creation in the 1930s, but its effect is still felt. Nylon opened the doors for other synthetic materials that are essential in modern life. Plastics could not have been created without the groundwork laid by Carothers with nylon. Synthetic rubber might not exist and the world might still be at the mercy of countries with natural rubber. Synthetic materials such as polyesters, acrylics, and polyolefins continue to be created, based on the methods used in the creation of nylon and their ductility, strength, and durability are constantly improving. The bullet proof Kevlar vest which protects police and many of the electronic gadgets that we use everyday are made from descendants of nylon.

In recent times, the green movement has grown in importance. In the battle of natural vs. artificial, many people would be quick to jump to the side of nature. Before they make this jump, they should look at the tag on their shirt. There is a high probability that nylon, polyester, or another synthetic material is shown. Human knowledge is a product of nature, and human knowledge created nylon. It is composed of purely natural substances and thus can be viewed as a simple rearrangement of "nature." Nylon can be recycled after its use in one application and applied to another. Coal can provide a limited amount of energy, but when it is used to produce nylon, its effect lasts longer. Nylon is more natural than most people realize. Nylon is a masterpiece of chemical technology.

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