NYLON at 50

An industrial success . . . and a personal tragedy

J. OTTON - 25/7/85

George B. Kauffman

→ P. ANTIKOW

Voir page 726

"I am making the first announcement of a brand new chemical textile fiber . . . the first man-made organic textile fiber prepared wholly from materials from the mineral kingdom. . . . [Nylon] is the generic name for all materials defined scientifically as synthetic fiber-forming polymeric amides having a protein chemical structure; derivable from coal, air and water, or other substances; and characterized by extreme toughness and strength and the peculiar property to be formed into fibers and into various shapes, such as bristles and sheets. . . .

"Though wholly fabricated from such common raw materials as coal, water and air, nylon can be fashioned into filaments as strong as steel, as fine as a spider's web, yet more elastic than any of the common natural fibers and possessing a beautiful luster. In its physical and chemical properties, it differs radically from all other synthetic fibers."

With this announcement 50 years ago, Charles Stine, vice president of research at E.I. du Pont de Nemours & Co., initiated the modern era of man-made polymers, The Age of Materials. Nylon's discovery by Wallace Hume Carothers and its development by chemists and chemical engineers at Du Pont constitute a triumph for basic industrial research.

It is a tragic irony of history that Wallace Hume Carothers (1896–1937) (Figure 1), the discoverer of nylon, who is revered today as the founder of American polymer chemistry, died by his own hand, convinced that he was a failure as a scientist. On April 29, 1937, just two days after his 41st birthday and three weeks after the basic patent on nylon had been filed, during one of his increasingly frequent attacks of depression, he committed suicide in a Philadelphia hotel room by drinking lemon juice containing potassium cyanide. He was survived by his wife, Helen Everett Carothers, who was employed at the Patent Division of Du Pont and who still resides in Wilmington. The couple had a daughter who was born on Nov. 26, 1937, almost seven months after her father's death.

In the words of James B. Conant (1893–1978), former professor of organic chemistry at Harvard University and later President of that institution, where Carothers had been an instructor, "Those of us in academic life . . always cherished the hope that some day he would return to university work. In his death, academic chemistry, quite as much as industrial chemistry, suffered a severe loss."

The eminent American organic chemist Roger Adams (1889–1971), who had been Carothers's mentor and who corresponded frequently with him for more than a decade, was aware of the mental affliction that had troubled him from his youth. For example, in a letter of July 24, 1934, to Carothers, Adams attempted to convince his former student that his obsessive feelings were unfounded:

"In regard to your complex that has led you to get a deflated interest in chemistry, I can only say that I know of no one who could justify such a feeling as this as little as yourself. If you don't realize it you should that your reputation in chemistry is very widespread, and that your ability to handle and make useful a wide fund of information in different branches of chemistry is the envy of all your friends, including myself. I can add also that the du Pont Company, as you well know, admires you and your work as they do no other chemist in the Company. If I have been able to help you in any way especially, I feel that I have not been able to do half as much for you as you rightfully deserve.

"So cheer up, you have nothing to be discouraged about, and I hope that you will soon be away from your present abode, and will either be on a vacation or back at work."

After 1935 Carothers's mental illness prevented him from playing any major role in the development of nylon. In June 1936 he suffered a nervous breakdown and spent five weeks in an institution in Philadelphia. After Carothers's death, Adams's consolatory letter of Dec. 6, 1937, to Carothers's father poignantly reveals the inability of his colleagues and friends to prevent his inexorable path toward self-destruction:

"I saw Wallace frequently and of course, knew that he had this mental disturbance which it was almost impossible for him to throw off. When I was with him he was seldom pessimistic although during the last year or so he showed more signs of it than ever before. When he was with me in Austria summer before last he seemed at all times to be perfectly normal and appeared to enjoy himself enormously. Apparently when he got by himself this obsession that he was a failure would come back and nothing seemed to help him.

"I need hardly to repeat to you that Wallace was probably more generally recognized internationally for his investigational work than any other organic chemist in the United States. His reputation here was of the best and he had practically a unanimous vote when he was elected to the National Academy. This is very unusual. The contributions which he has made, both scientifically and industrially, will undoubtedly be lasting. His many friends and I particularly were agreed that we could do nothing to help him out of the mental state which had developed in the last few years."

A moody perfectionist

Carothers was born in Burlington, Iowa, on April 27, 1896, the oldest of four children. His forebears on both sides of the family were great lovers of music, which may account for Wallace's great interest in and appreciation for music. In later life he remarked that if he could live his life over again, he would be a musician. He was especially devoted to his sister, Mrs. Isabel Carothers Berolzheimer, who was Lu of the radio trio Clara, Lu, and Em, and her death on Jan. 7, 1937, less than four months before Carothers's suicide, was a terrible shock to him and probably hastened his untimely demise.

Wallace's family moved to Des Moines, Iowa, when he was five, and he was educated in the public schools of that city, graduating from North High School in 1914. He enjoyed tools and mechanical devices, and he devoted much time to various experiments. Even at this age he was a moody perfectionist. He was thorough in his school work and left no task unfinished or done in a careless manner. In July 1915 he graduated (in much less than the usual time) with a major in accounting and secretarial studies from Capital City Commercial College in Des Moines, where his

Naming the new product

In his announcement Stine used the term *nylon* publicly for the first time. According to E. K. Gladding, director of the newly formed Nylon Division of Du Pont's Rayon Department, the name *norun* was first suggested because of the resistance of nylon stockings to snagging, but this name was not desirable for numerous reasons. Gladding's daughter suggested that *norun* be spelled backward as *nuron*, but the Naming Committee decided that this sounded like a nerve tonic. A suggestion was made to change the *r* to *l*, giving *nulon*, but the Legal Department considered this name too similar to another registered trademark. Someone suggested changing the *u* to *i*, giving *nilon*, but it was feared that this name might be mispronounced. Finally, the *i* was changed to *y*, and the name *nylon* was born.

Une autre explication du mot 'NYLON'

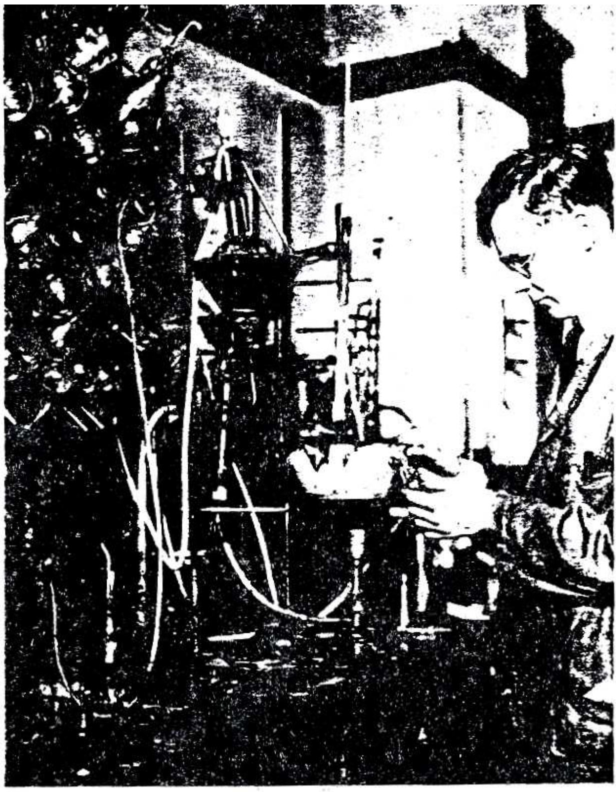


Figure 1. Carothers at the bench

father taught. In the fall of 1915, he used his business training to obtain a teaching position in the Commercial Department of Tarkio College, Tarkio, Mo., where he simultaneously pursued a course of studies in chemistry leading to his B.S. degree in 1920. Initially undecided on a career choice, his transcript shows that he was no narrow specialist but was at the head of his class in virtually every course.

In a letter to Betty Jo Travis dated Feb. 12, 1947, Arthur McCay Pardee (1885–1962), instructor in chemistry and physics at Tarkio College who stimulated Carothers's interest in chemistry, recalled, "I well remember him when he decided on chemistry as a career. I had a number of talks with him in which I showed him that the sky was the limit on what he could accomplish." In a biographical memoir written after Carothers's death Pardee wrote, "His interest in chemistry and the physical sciences was immediate and lasting, and he rapidly outdistanced his classmates in accomplishment."

A brilliant student

After graduating, Carothers attended the University of Illinois at Urbana, which then as now had one of the best graduate schools of chemistry in the United States. Completing the requirements for his M.A. degree in one year (1921), but lacking funds for further study, he became a temporary instructor in analytical and physical chemistry for the academic year 1921–1922 at the University of South Dakota at Vermilion, where his former teacher, Dr. Pardee, was chairman of the chemistry department. Here, in Pardee's words, Carothers "was still the same quiet, methodical worker and student, not brilliant as a lecturer, but careful and systematic in his contact with the students. . . . [He] literally spent all his time not teaching . . . [in] investigations in the laboratory. A number of his newly found friends in South Dakota tried to induce him to relax somewhat from his constant and sustained application to work, but without avail. He seemed to be driven by the many things that occurred to him as worth investigating in the laboratory . . . his friends regarded him as a very brilliant personality who was almost overwhelmed with the things to do, and his later career certainly justified their estimate."

At South Dakota the 25-year-old Carothers produced two significant research papers, both of which appeared in the *Journal of the American Chemical Society*—"The Isosterism of Phenyl Isocyanate and Diazobenzene-Imide" (1923) and "The Double Bond" (1924). In the second paper he presented "the first clear, definite application of the [Lewis–Langmuir] electronic theory to organic chemistry on a workable basis."

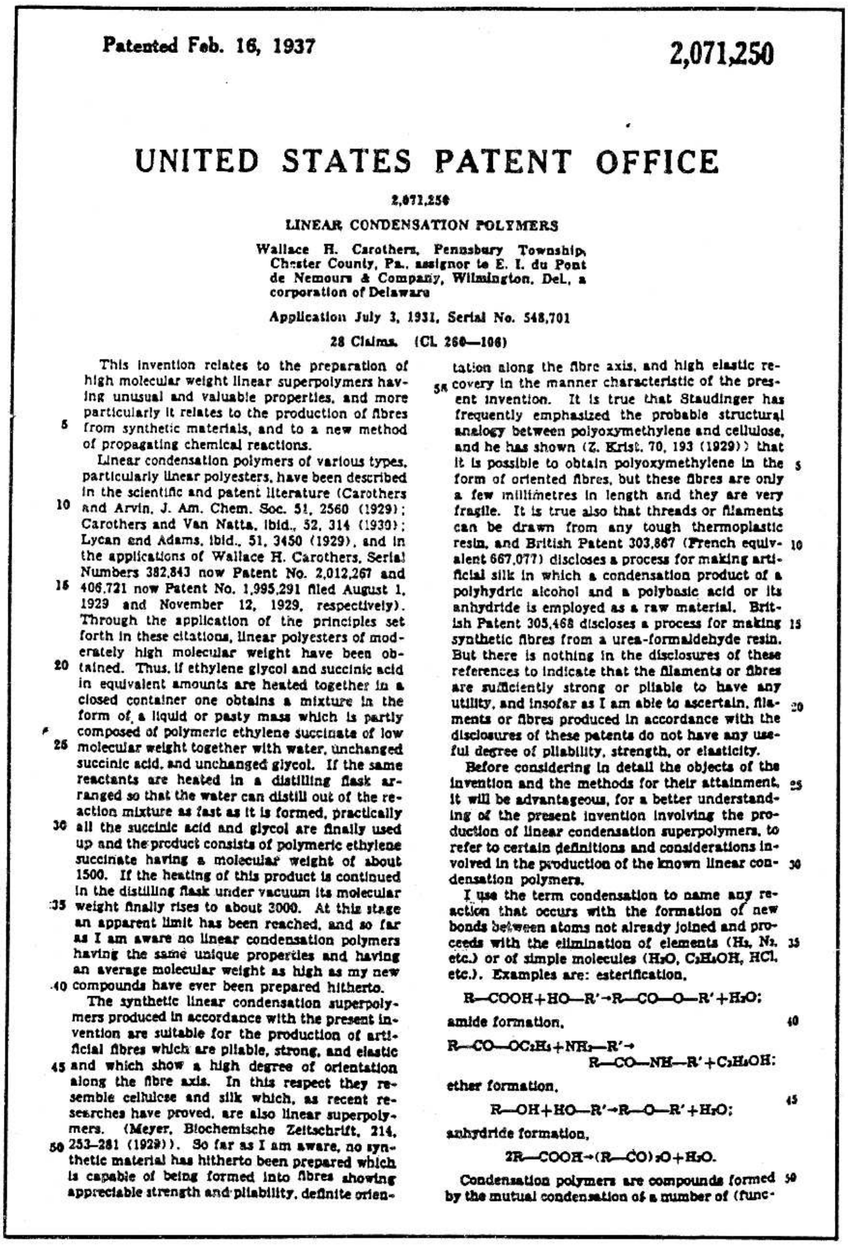
In 1922 Carothers returned to Urbana, where he earned his doctorate in organic chemistry (1924), under Adams's supervision, with a dissertation on hydrogenations with modified platinum oxide–platinum black catalysts and on the effect of promoters and poisons on these catalysts in the reduction of various organic compounds. During 1922–1923 he was a research assistant, and during 1923–1924 he held the Carr Fellowship, the highest award offered by the chemistry department. On his graduation the faculty considered him "one of the most brilliant students who has ever been awarded the doctor's degree at the University of Illinois."

Carothers at Harvard

Carothers was instructor in chemistry at the University of Illinois from 1924 to 1926, and at Harvard University from 1926 to 1928. According to Conant, "In his research, Dr. Carothers showed even at this time that high degree of originality which marked his later work. He was never content to follow the beaten track or to accept the usual interpretations of organic reactions. His first thinking about polymerization and the structure of substances of high molecular weight began while he was at Harvard."

During Carothers's first semester at Harvard, Charles Milton Altland Stine (1882–1954), Director of Du Pont's Chemical Department, made a proposal to the company's management that was destined to result ultimately in Carothers's discovery of nylon and the materials revolution that it was to spawn. In a memorandum to Du Pont's Executive Committee on Dec. 18, 1926, Stine proposed, "We are including in the central Chemical Department's budget for 1927 an item of $20,000 to cover what is for want of a better name Pure Science or Fundamental Research Work . . . with the object of discovering new scientific facts," rather than trying to invent new products or improve existing ones. Although this type of research had been carried out successfully by industry in Germany and by the General Electric Company in the United States, it represented an innovative, radical departure from common American industrial practice at that time.

Herbert Hoover, "the great engineer," soon to become



Patented Feb. 16, 1937 2,071,250

UNITED STATES PATENT OFFICE

2,071,250

LINEAR CONDENSATION POLYMERS

Wallace H. Carothers, Pennsbury Township, Chester County, Pa., assignor to E. I. du Pont de Nemours & Company, Wilmington, Del., a corporation of Delaware

Application July 3, 1931, Serial No. 548,701

28 Claims. (Cl. 260—106)

This invention relates to the preparation of high molecular weight linear superpolymers having unusual and valuable properties, and more particularly it relates to the production of fibres from synthetic materials, and to a new method of propagating chemical reactions.

Linear condensation polymers of various types, particularly linear polyesters, have been described in the scientific and patent literature (Carothers and Arvin, J. Am. Chem. Soc. 51, 2560 (1929); Carothers and Van Natta, ibid., 52, 314 (1930); Lycan and Adams, ibid., 51, 3450 (1929), and in the applications of Wallace H. Carothers, Serial Numbers 382,843 now Patent No. 2,012,267 and 406,721 now Patent No. 1,995,291 filed August 1, 1929 and November 12, 1929, respectively). Through the application of the principles set forth in these citations, linear polyesters of moderately high molecular weight have been obtained. Thus, if ethylene glycol and succinic acid in equivalent amounts are heated together in a closed container one obtains a mixture in the form of a liquid or pasty mass which is partly composed of polymeric ethylene succinate of low molecular weight together with water, unchanged succinic acid, and unchanged glycol. If the same reactants are heated in a distilling flask arranged so that the water can distill out of the reaction mixture as fast as it is formed, practically all the succinic acid and glycol are finally used up and the product consists of polymeric ethylene succinate having a molecular weight of about 1500. If the heating of this product is continued in the distilling flask under vacuum its molecular weight finally rises to about 3000. At this stage an apparent limit has been reached, and so far as I am aware no linear condensation polymers having the same unique properties and having an average molecular weight as high as my new compounds have ever been prepared hitherto.

The synthetic linear condensation superpolymers produced in accordance with the present invention are suitable for the production of artificial fibres which are pliable, strong, and elastic and which show a high degree of orientation along the fibre axis. In this respect they resemble cellulose and silk which, as recent researches have proved, are also linear superpolymers. (Meyer, Biochemische Zeitschrift, 214, 253–281 (1929)). So far as I am aware, no synthetic material has hitherto been prepared which is capable of being formed into fibres showing appreciable strength and pliability, definite orientation along the fibre axis, and high elastic recovery in the manner characteristic of the present invention. It is true that Staudinger has frequently emphasized the probable structural analogy between polyoxymethylene and cellulose, and he has shown (Z. Krist. 70, 193 (1929)) that it is possible to obtain polyoxymethylene in the form of oriented fibres, but these fibres are only a few millimetres in length and they are very fragile. It is true also that threads or filaments can be drawn from any tough thermoplastic resin, and British Patent 303,867 (French equivalent 667,077) discloses a process for making artificial silk in which a condensation product of a polyhydric alcohol and a polybasic acid or its anhydride is employed as a raw material. British Patent 305,468 discloses a process for making synthetic fibres from a urea-formaldehyde resin. But there is nothing in the disclosures of these references to indicate that the filaments or fibres are sufficiently strong or pliable to have any utility, and insofar as I am able to ascertain, filaments or fibres produced in accordance with the disclosures of these patents do not have any useful degree of pliability, strength, or elasticity.

Before considering in detail the objects of the invention and the methods for their attainment, it will be advantageous, for a better understanding of the present invention involving the production of linear condensation superpolymers, to refer to certain definitions and considerations involved in the production of the known linear condensation polymers.

I use the term condensation to name any reaction that occurs with the formation of new bonds between atoms not already joined and proceeds with the elimination of elements (H_2, N_2, etc.) or of simple molecules (H_2O, C_2H_5OH, HCl, etc.). Examples are: esterification,

$$R{-}COOH + HO{-}R' \rightarrow R{-}CO{-}O{-}R' + H_2O;$$

amide formation,

$$R{-}CO{-}OC_2H_5 + NH_2{-}R' \rightarrow R{-}CO{-}NH{-}R' + C_2H_5OH;$$

ether formation,

$$R{-}OH + HO{-}R' \rightarrow R{-}O{-}R' + H_2O;$$

anhydride formation,

$$2R{-}COOH \rightarrow (R{-}CO)_2O + H_2O.$$

Condensation polymers are compounds formed by the mutual condensation of a number of (func-

***Figure 2.* The patent**

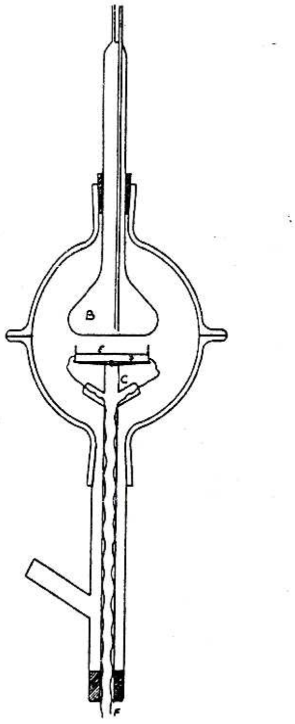


***Figure 3.* Carothers's molecular still: the critical apparatus**

the 31st president of the United States, had argued that the accelerated pace of industrial research was rapidly depleting the supply of scientific knowledge that constituted its source. Stine agreed, stating that "applied research is facing a shortage of its principal raw materials." He cited four reasons why Du Pont should support his new program: the scientific prestige or "advertising value" resulting from the presentation or publication of papers; the research would improve morale and facilitate recruiting of chemists; the results could be used to exchange research information with other companies; and basic research might lead to practical applications. Stine strongly believed in the inevitability of this last reason, but he felt that the first three reasons were sufficient to justify his program.

Stine proposed five areas of research for his program: colloid chemistry; catalysis; production of physical and chemical data; organic synthesis; and polymerization. He believed that Du Pont might benefit materially from research on polymerization because almost nothing was "known about the actual mechanism of the change which takes place, so that the methods used are based almost solely on experience." He recognized that his program would succeed only if he could recruit the best scientists in the above five fields, but he was able to hire only two young men with the proper academic experience—a 30-year-old Elmer O. Kraemer from the University of Wisconsin (colloid chemistry) and a 31-year-old Carothers from Harvard (polymerization).

Carothers did not immediately accept Stine's offer, which was first made in the summer of 1927; he accepted only after several months of negotiations in which he sought assurance that his research efforts would be unrestricted. He was not certain that the increase in annual salary—$5000 compared to Harvard's $3200—would compensate him for the loss of "the real freedom and independence and stability of a university position." He was concerned about possible problems in adapting to an industrial milieu because he suffered "from neurotic spells of diminished capacity which might constitute a much more serious handicap there [at Du Pont] than here [at Harvard]," especially since he had undergone a difficult period of adjustment after his move from Illinois to Harvard.

Stine wrote to Carothers that, "We are interested in you because we believe you will not only do work of a high order, but also that you will select worthwhile problems, and we therefore anticipate no difficulty with respect to decisions about the particular investigations you would want to undertake. I mean worthwhile from a scientific point of view and not from the point of view of direct financial returns." In October 1927, Carothers rejected Stine's offer of Sept. 20, 1927, but 10 days after Stine's assistant Hamilton Bradshaw had visited Carothers at Cambridge, Carothers accepted the offer to head Du Pont's organic group in fundamental research at its Experimental Station.

In February 1928 Carothers arrived in Wilmington, and by October he and three co-workers were investigating materials of high molecular weight. Although today about half of American chemists work on the preparation, characterization, or application of polymers, the concept of high molecular weight molecules won general acceptance only in the 1930s, largely as a result of Carothers's pioneering work at Du Pont.

Classical organic chemistry was concerned primarily with well-defined compounds that could be characterized by such traditional methods for determining molecular weights as freezing-point depression and boiling-point elevation. On the other hand, as late as the early 1920s the study of natural organic substances of high molecular weight was a field hardly considered worthy of a respectable organic chemist and was condescendingly referred to as *Schmierenchemie* (grease chemistry) because of the properties of many of these compounds. At that time the German chemist Hermann Staudinger (1881–1965) abandoned all his work on low molecular weight substances and devoted himself exclusively to macromolecular chemistry, a field which he founded and in which he was the principal investigator.

Macromolecules and superpolyesters

Most chemists then adhered to the association theory, which considered high polymers to be aggregates of monomer molecules (micelles) bound loosely together in some ill-defined way by "partial valences" or even weak residual van der Waals forces. On the contrary, Staudinger maintained that high polymers were actually giant molecules or "macromolecules" (a term that he coined in 1922) held together by ordinary covalent bonds. Carothers's fundamental work on polymers firmly established modern polymer theory and helped convince skeptics of the validity of Staudinger's views. Staudinger received the Nobel Prize in chemistry in the relatively late year of 1953 "for his discoveries in the field of macromolecular chemistry."

In his attempt to resolve the controversy between proponents of the macromolecular theory and those of the association theory, Carothers began his research program by subjecting well-known compounds to standard organic chemical reactions so that they formed long-chain molecules whose structure was unequivocally established. By April 1930, in the course of their incidental study of the chemistry of mono- and divinylacetylene, Carothers and his colleagues found that the first compound reacted with hydrogen chloride to produce a liquid called chloroprene (2-chloro-1,3-butadiene), which, in turn, polymerized spontaneously to yield a rubberlike solid called neoprene, the first commercially successful synthetic rubber made in the United States. Neoprene was found to be superior to natural rubber for applications requiring special properties such as resistance to oils, solvents, chemicals, air, heat, and flame. In July 1930 Carothers and his colleague Julian Werner Hill produced the first forerunner of nylon, and the patent for linear-condensation polymers was filed in July 1931 (Figure 2).

Within an extremely short time Carothers achieved a reputation as *the* outstanding American researcher in high polymer chemistry. In 1929 he was made associate editor of the prestigious *Journal of the American Chemical Society*, and in 1930 he became an editor of *Organic Syntheses*. Active in the Organic Chemistry Division of the American Chemical Society, he was often invited to speak before various scientific groups. In 1936 he was elected to the National Academy of Sciences, the first industrial organic chemist to be so honored. In the field of polymerization he published 31 papers and held 50 patents.

Carothers used a molecular still (Figure 3) to eliminate the byproduct water more efficiently, which allowed polymerization to proceed to a greater extent, resulting in substances with molecular weights of 10,000–20,000. According to Elmer Keiser Bolton (1886–1968), who had succeeded Stine as director of the Fundamental Research Program in June 1930, "without this technique Carothers might have failed in his search for superpolymers."

Hill found that filaments of these superpolyesters could be pulled like taffy into fibers by a process that he called "cold drawing," which, according to X-ray diffraction patterns, oriented the polymer chains along the fiber axis. This technique made the fibers more pliable, elastic, flexible, and tough, and it is still used today in the production of most synthetic textiles, rug piles, fishing line, and tire cords.

Carothers's group then began "practical" research to determine whether these long-chain polyesters (formed from glycols and dicarboxylic acids) could form useful textile fibers. Unfortunately, these first materials were unsuitable for synthetic fibers because they melted below the boiling point of water (100 °C), were only moderately stable in water, and were soluble in various solvents. Carothers therefore modified the condensation methods that he had used for superpolyesters. He substituted organic compounds with amine groups at both ends (diamines) for glycols in the reaction with dicarboxylic acids. Water was again formed as the byproduct, but the main product was now a higher melting, more inert superpolyamide—a long-chain polymer held together by amide bonds. Called peptide bonds in the case of natural products, these are the bonds that hold together proteins such as natural silk.

The polymers were designated by two numbers—the first corresponding to the number of carbon atoms in the monomeric diamine and the second corresponding to the number of carbon atoms in the monomeric dicarboxylic acid. For several years, during which he considered abandoning the project, Carothers and his co-workers systematically prepared polyamides from various combinations of diamines and dibasic acids. By spring 1935, he decided that the polyamide prepared from pentamethylenediamine and sebacic acid (Fiber 510) was the best candidate for a textile fiber because its fibers were elastic, stronger than silk, and inert to moisture and solvents.

Bolton, however, insisted that the high cost of its starting materials and its still relatively low melting point (196 °C) made it commercially unsuitable. Instead, he favored the polyamide prepared from hexamethylenediamine and adipic acid—poly(hexamethylene adipamide) (Fiber 66). This polymer, first synthesized by Carothers on Feb. 28, 1935, was insoluble in common solvents, had a melting point of 263 °C and, in Bolton's estimation, possessed the "best balance of properties and manufacturing cost of the polyamides then known."

The 66 polyamide

After the 66 polyamide had been selected as the most suitable candidate for commercial production, development of a practical manufacturing process was relegated to other groups. The starting materials for the production of nylon—adipic acid and hexamethylenediamine—were mere laboratory curiosities at the time, and no manufacturing plants in the world could then produce either of them in the large quantities required. By 1936 Roger Williams of Du Pont's Ammonia Department had developed a new catalytic process for the production of adipic acid from phenol (carbolic acid), which was to be carried out at the company's plant at Belle, W.V. A new process for the commercial production of hexamethylenediamine from adipic acid was similarly developed.

A pilot plant for the production of 66 polyamide was completed in Wilmington in July 1938, the same month in which the material was introduced on the market as "Exton" bristles for Dr. West's toothbrushes. On Oct. 27, 1938, at the *New York Herald Tribune*'s Eighth Annual Forum on Current Problems, held at the soon to be opened New York World's Fair, Stine, made the statement with which we opened the article. It burst like a bombshell.

A commercial triumph

The development of nylon had not been quick, easy, or inexpensive. Du Pont had spent an estimated $27 million during the 11 years that elapsed between the inception of Stine's fundamental research program and the production of nylon in the first large-scale commercial plant at Seaford, Del. Construction of this plant, designed initially to produce 3 million pounds of yarn annually, began in January 1939. Before the first unit was in operation, the planned capacity was increased to 4 million pounds, and before the first plant was completed this figure was doubled to 8 million pounds.

In February 1939, Stine's promise of hosiery made of nylon was fulfilled when nylon stockings were exhibited at the Golden Gate International Exposition in San Francisco and were sold first to Du Pont employees. In April 1939

Figure 4. Betty Grable contributes her "nylons" to the war effort.

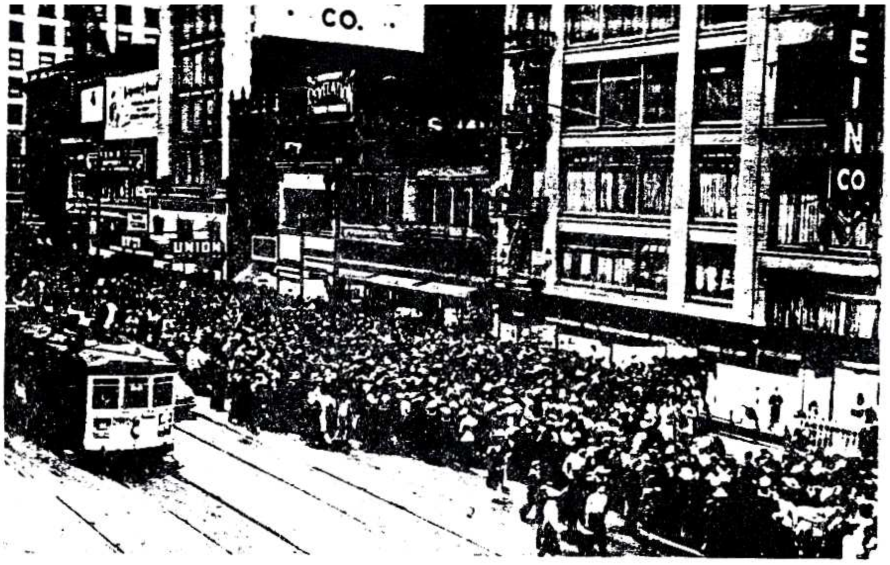


Figure 5. **Post-war nylon stocking sale (1945)**

they were displayed at the New York World's Fair. On Oct. 24, 1939, they were sold to Wilmington, Del., residents only, and on May 15, 1940, they went on sale throughout the country. In New York City alone, 4 million pairs were sold within a few hours. In January 1940 the Seaford plant began full-scale production. Less than five years had elapsed between Carothers's laboratory synthesis of the 66 polyamide and commercial production of nylon yarn—a virtually unprecedented achievement in the history of American industrial enterprise.

In this triumph Stine, Bolton, and Carothers played specific, indispensable roles, as John K. Smith and David A. Hounshell have noted. Stine's fundamental research program was necessary to woo Carothers, the discoverer, from academia to an industrial laboratory. Carothers himself admitted, "If I had been asked to do research on anything that I pleased with the mutual understanding that the object was to develop something that would bring in a direct profit, I should never have accepted the job." However, if Carothers had been left entirely to follow his own wishes and interests, in strict accordance with Stine's fundamental research program, he probably would not have discovered neoprene and nylon.

Bolton, who was apparently suspicious of fundamental research in industry and who had originally opposed the program that he was later chosen to supervise, emphasized Stine's fourth and initially nonessential reason for his program—"practical applications." Bolton's pragmatic attitude, along with the exigencies of the Great Depression, which demanded results in return for funds expended, served to transform Carothers's theoretical research into commercially significant products. In the words of R. C. Forney at Carothers's posthumous induction into the National Inventors Hall of Fame in April 1984, "both fundamental research, symbolized by Carothers, and the commercial guidance of that research, symbolized by Bolton, are necessary for innovation that will affect society's needs."

Before the advent of nylon, the United States and much of the world was dependent on Japan for silk. Nylon is closer to silk in both constitution and properties than any other fiber, natural or artificial, possessing silk's appearance and luster. Nylon appeared on the market just in time to replace the supply of natural silk from the Orient that was cut off during World War II. In February 1942, the U.S. War Production Board commandeered all production of nylon exclusively for military uses, and pre-war nylon stockings were donated by thousands of patriotic American women to make parachute cloth, "flak curtains" and "flak vests," tow ropes, tire cords, fabric, and other items vital to the war effort (Figure 4).

Nylon stockings were made available again in 1945 after the war had ended, and women crowded into lines blocks long outside the stores (Figure 5). It took three years for the hosiery shortage to end.

A new era in the history of nylon had begun. Most of the military applications suggested possible new post-war uses when nylon returned to domestic use. It led the way to the present multitude of man-made fibers, which have revolutioned the textile and plastics fields.

Because of its unique properties, nylon has found an incredible variety of applications—from clothes to gears and bearings, from fishing line and plastic bags to airplane parts. Nylon has become the prototypical example of basic research that begins with no practical end use in mind but that results in an almost endless array of new products that enrich our daily lives. To foreigners it is a symbol of modern American industrial achievement.

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