THE BECKMAN CENTER FOR THE HISTORY OF CHEMISTRY

STEPHANIE LOUISE KWOLEK

Transcript of an Interview
Conducted by

Raymond C. Ferguson

in

Sharpley, Delaware

on

4 May 1986

STEPHANIE KWOLEK

THE BECKMAN CENTER FOR THE HISTORY OF CHEMISTRY

Oral History Program

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STEPHANIE LOUISE KWOLEK

1923 Born in New Kensington, Pennsylvania, on 31 July

Education

1946 B.S., chemistry, Carnegie-Mellon University
Some graduate courses in chemistry

Professional Experience

E. I. du Pont de Nemours & Co., Inc.

1946-1959	Chemist
1959-1967	Research Chemist
1967-1974	Senior Research Chemist
1974-1986	Research Associate

Honors

1959	Publication Award, Delaware Section, American Chemical Society
1976	Howard N. Potts Medal, Franklin Institute of Philadelphia
1978	Award for Contributions to "Kevlar" (DuPont trademark for aramid fiber), American Society for Metals
1980	Chemical Pioneer Award, American Institute of Chemists
1980	Award for Creative Invention, American Chemical Society
1981	Honorary Doctor of Science degree, Worcester Polytechnic Institute
1983	Alumni Association Merit Award, Carnegie-Mellon University
1985	Engineering/Technology Award, Society of Plastics Engineers
1985	Polymer Processing Hall of Fame, University of Akron
1988	Harold DeWitt Smith Memorial Award, American Society of Testing Materials
1990	Du Pont Honoree at the Bicentennial Celebration of the United States Patent and Copyright Laws

ABSTRACT

Stephanie Kwolek starts this interview by talking about her family background. Her father's early death meant that her mother had to work to support Kwolek and her brother, who became a chemical engineer. At Carnegie Institute of Technology, Kwolek shifted her interests from medicine to chemistry. Deciding to enter industry, she accepted a position with the Rayon Department of Du Pont at Buffalo. Here she started her career in polymer synthesis and worked with Izard, Wittbecker, and Morgan. When the laboratory moved to Wilmington, Kwolek was associated with the low-temperature polymerization program; she discusses the nylon rope trick, Du Pont promotion policy, and liquid crystalline polymers. The interview concludes with her reflections on colleagues and Du Pont consultants.

INTERVIEWER

Raymond C. Ferguson obtained his degrees in chemistry from Iowa State University (B.S., M.S.) and Harvard University (Ph.D.). He worked in research divisions of the Organic Chemicals, Elastomer Chemicals, and Central Research Departments of Du Pont, principally in molecular spectroscopy, organic structure analysis, and polymer characterization. Currently he is affiliated with CONDUX, Inc., a consulting association of ex-Du Pont professionals.

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INTERVIEWER: Raymond C. Ferguson

LOCATION: Sharpley, Delaware

DATE: 4 May 1986

FERGUSON: You were born in New Kensington, Pennsylvania, in 1923. Would you tell me something about your family? What was your father's name?

KWOLEK: My father's name was John and my mother was Nellie Zajdel (pronounced Zidel).

FERGUSON: What was your father's origin?

KWOLEK: Both of my parents were born in Poland. However, my mother's father had emigrated to this country sometime in the 1890s. I believe my maternal grandmother died when my mother was born. My mother was raised by her grandmother and by an older only sister until she was a teenager, at which time she emigrated to the United States. My mother's sister preceded her to the United States.

FERGUSON: Were they from the same part of Poland?

KWOLEK: Yes, they both came from Krosno in Poland, which is in the southern part of the country near Kraków.

FERGUSON: What age was your father when he came over?

KWOLEK: He was a young man, but I have no idea what his age was.

FERGUSON: What work did he do?

KWOLEK: I think he was a molder for a small foundry in New Kensington, Pennsylvania.

FERGUSON: Did he die early?

KWOLEK: Yes, he did. He was about forty when he died. He had a hernia operation, developed pneumonia after the surgery, and died.

FERGUSON: How old were you when he died?

KWOLEK: I was about ten years of age and my brother was two years younger than I. Since there were no Social Security benefits, my mother was forced to work outside of the home.

FERGUSON: How did she support you?

KWOLEK: She worked for the Aluminum Company of America in the "Wearever" Department, which is the department that manufactures pots and pans and "Kensingtonware." The latter, I believe, is no longer being made. In addition, she had a number of miscellaneous jobs.

FERGUSON: Did your parents have a high school education?

KWOLEK: I would say they had the equivalent of a high school education. I do remember that both of them were constant readers. My father was knowledgeable in house-building, and designed and built furniture at home. He spent much time working in the garden, grafting trees and hybridizing flowers. I remember him as quite an experimentalist in whatever he did. My mother, of course, was primarily a homemaker--a great cook and an excellent seamstress. In addition, she was very entertaining at storytelling.

FERGUSON: Would you tell me something about your brother Stanley [John]?

KWOLEK: He is two years younger than I am--he was born in November of 1925. He graduated from Carnegie-Mellon University [then Carnegie Institute of Technology] as a chemical engineer with a bachelor of science degree. I remember that he was gifted in mathematics as a child. He also attended the University of Kentucky in Lexington. This was in the 1940s when he and his entire college class were inducted into the army during World War II. There he studied civil engineering at the army's request. His group was destined for the invasion of Normandy, but fortunately, he was one of the few who were kept in the States. After he was discharged from the army, he came back to Carnegie-Mellon University and finished his course work in chemical engineering. After graduation he accepted a position with Gulf Oil in their research laboratories in Harmarville, Pennsylvania.

FERGUSON: How long did he stay there?

KWOLEK: He stayed there until several years ago, when Gulf was acquired by Chevron. This was a very sad time for him and his coworkers.

FERGUSON: Was he director of research?

KWOLEK: No, but he had management/research responsibilities on a high level.

FERGUSON: It's interesting that you both went into science. How did that arise?

KWOLEK: I really don't know. I had many interests. I remember as a child, I tormented the neighborhood children with playing school, in which I always was the teacher. So, obviously, I was very interested in teaching. Then, I spent a great deal of time (as a child) in fashion designing. I made hundreds of dresses and outfits--on paper, of course. I did some writing. I wrote some poetry and short stories.

I had no chemistry or physics in high school, but I did have math, biology and general science. I was a good student. When I graduated from high school I was very much interested in medicine. So I enrolled in a course of study with much science. I worked twenty hours a week that first year and made the honor roll much to my surprise.

FERGUSON: Did you go to public or parochial schools?

KWOLEK: It was sort of a mishmash. I spent the first four years in a public school, and the next four years in a parochial school. I graduated from a parochial grade school. Then, I went two years to a public high school, and two years to a private high school.

FERGUSON: Why? Were the private schools better than the public schools in New Kensington?

KWOLEK: No. They were about as good as most private schools.

FERGUSON: Did you stay in New Kensington after your father died?

KWOLEK: Yes. We continued living in New Kensington. I walked about two miles a day going to and coming from school. Bus service was not available. After my sophomore year I had some leg surgery. It was then that I found it necessary to have private schooling.

FERGUSON: Was this a boarding school?

KWOLEK: Yes, partly.

FERGUSON: Where was it located?

KWOLEK: It was in the Pittsburgh area.

FERGUSON: What were the physical infirmities that brought on the surgery?

KWOLEK: I don't know. It's a very long and complicated story with a lot of guessing. It involves bone structure and possibly a defective gene. However, initially the condition was blamed on a very severe case of measles in infancy. This may have been a factor. Medicine was rather primitive in those days.

FERGUSON: You didn't have polio or anything like that?

KWOLEK: No. Whatever it was, I led an active life as a child.

FERGUSON: I recall that you had a real bout with knee surgery about five or maybe eight years ago?

KWOLEK: That's right.

FERGUSON: That's too bad. Well, it didn't slow you down in those days, anyway.

KWOLEK: No, it didn't. I was not pampered. I realized early in life that it was a matter of sink or swim.

FERGUSON: Do you recall any teacher that had a particular influence on you in terms of your later career?

KWOLEK: In my sophomore year (high school), I had a social science teacher, Jessie B. Moore, who was very nice to me. I admired her very much, and she encouraged me. I think she had more of an influence on me than anyone else at that stage of my life. Then, of course, I had two chemistry professors in college that I admired very much--Dr. Clara Miller and Clara Jane Douglas. Both of them are no longer living.

FERGUSON: You got your bachelor of science degree in four years. Was your major chemistry?

KWOLEK: Yes. You know, when I applied, women were not admitted to the College of Engineering at Carnegie-Mellon University (then Carnegie Institute of Technology). All women went to the Margaret Morrison Carnegie College, or the Fine Arts College. My degree is from Margaret Morrison, but I took chemistry courses in both the College of Engineering and in Margaret Morrison. The classes were not large, so we received much individual attention. Also, there was a wide variety of chemistry courses to choose from between the two colleges.

FERGUSON: Did you live as a resident student there?

KWOLEK: There was one year (maybe two) when I commuted. The first year I lived in a home near the school and worked there twenty hours a week. The next year or two I lived at home and commuted between New Kensington and Carnegie. The last year I lived on the Carnegie campus.

FERGUSON: Did you have a minor?

KWOLEK: Yes, it was biology.

FERGUSON: What was your goal?

KWOLEK: I was still thinking of medicine at that point. That is why I was taking biology courses, together with chemistry, physics and math.

FERGUSON: How did you support yourself?

KWOLEK: I worked summers and I had scholarships. One of them was a state scholarship that I used throughout the years. I also had a Carnegie scholarship which was given because of my high academic standing. This I never used.

FERGUSON: You obviously had a good high school record. Were you valedictorian?

KWOLEK: No. We didn't have a valedictorian when I graduated from high school. There were less than a dozen students in the class.

FERGUSON: You said that Carnegie-Mellon was small. How many were in your class there?

KWOLEK: I think there were about twelve in the science class.

FERGUSON: Were you the only woman?

KWOLEK: No. I went to Margaret Morrison, which was strictly for women. So when I got my degree from Margaret Morrison, there were about a dozen women that majored in chemistry or in biology.

FERGUSON: Did you attend classes with the men?

KWOLEK: Some of the classes.

FERGUSON: Were the classes all taught at Carnegie?

KWOLEK: Yes, but in various colleges within the Carnegie Institute of Technology.

FERGUSON: What are your recollections of New Kensington and Pittsburgh in those days?

KWOLEK: Well, New Kensington was a very small town, but it was important industrially because of the location of the Aluminum Company of America and the Aluminum Company of America Research Laboratory. Gulf Research Laboratory in Harmarville was about fifteen miles away. The Pittsburgh Plate Glass Company was a little bit up the river. Many of the industrial labs were located in the Pittsburgh area, and New Kensington was located about twenty miles northeast of Pittsburgh. There was a commuter train running between New Kensington and Pittsburgh, so it was very easy to get back and forth. There were buses running every half an hour, so it was no problem traveling to Pittsburgh, and especially to the Shadyside area where Carnegie-Mellon was

located. The school was located about a mile from the Shadyside train station. In those days a fast mile or two walk was really nothing. [laughter]

FERGUSON: I remember that Pittsburgh was an awfully dirty, smoky place back in the forties.

KWOLEK: Well, I rarely got into that area. My world revolved around the Shadyside area and occasionally downtown Pittsburgh.

FERGUSON: You were talking earlier about your desire to go into medicine.

KWOLEK: I was interested in medicine. When I was in college I worked during the summertime. After my sophomore year, I worked in the School of Biochemistry of the University of Pittsburgh. The laboratory was located in the same building as the School of Medicine. It was a very interesting and illuminating summer. I realized that life was very hard for a woman in medical school.

FERGUSON: Did you have a lab job?

KWOLEK: Yes, I worked in a laboratory and I was involved in research on porphyrin. I also took part in the weekly seminars. I remember having to prepare and give a talk on my work before an important visitor (scientist) from Europe. It was a delightful and exciting time for me.

They wanted me to come back the following summer, but the pay was not very good, and I needed the money. So the next summer, I worked for Gulf Oil in the Harmarville research lab, and that work I also enjoyed very much. The work involved fractionation of gasoline. I did a lot of mathematical calculations while I was there. When I graduated from college, I was still thinking about going to medical school, but I realized it was going to take an awful lot of money aside from any financial help that I may have gotten. I decided that I would take a temporary job, save some money and then go back to school. At the time, I interviewed with Gulf Research and Development Company and Du Pont and some smaller companies. I decided that the work at Du Pont was the most interesting. In addition, the starting salaries were the same for men and women at Du Pont. This was not the case for some other companies.

FERGUSON: Did you go directly to Buffalo?

KWOLEK: Yes, I went directly to Buffalo. At that time Dr. Hale W. Charch was the research director. He was a brilliant person, but rather eccentric. Of course you know, he was the inventor of moisture-proof cellophane. I remember he interviewed me, and then he said he would let me know in a few weeks as to whether he would hire me. I said that I really would like to know immediately whether he was interested, because I was considering other jobs as well, and some pressure was being put on me to reply to these companies. So, he called in his secretary and in my presence dictated a letter in which he made me an offer of a job. [laughter] I took the letter home with me and thought about it a few days, and then I replied to him, accepting his offer.

FERGUSON: Was this in the Film Department?

KWOLEK: No, this was then the Rayon Department of the Du Pont Company; later it became the Textile Fibers Department. The plant and laboratory were located on River Road in Buffalo.

FERGUSON: Was that called the Yerkes Laboratory?

KWOLEK: Yes, the Yerkes Laboratory.

FERGUSON: Wasn't it a little bit unusual for you to be hired as a chemist with only a B.S. degree?

KWOLEK: Yes, it was unusual to be hired with just a B.S. degree, but Dr. Charch was unusual. I was not the only such person to be hired at that time.

FERGUSON: Do you think that was due to your previous experience?

KWOLEK: Yes, I think that was a factor. Of course, I had quite a bit of laboratory experience, and I had an excellent record in college--I had just about all A's. Also, I did some research on the side while I was in college and I wrote some papers.

FERGUSON: Are they published?

KWOLEK: No, they were not published.

FERGUSON: Were they like a senior thesis?

KWOLEK: Yes, I would say that they were.

FERGUSON: Were they part of the curriculum?

KWOLEK: It was an elective. I had many opportunities for electives. Classes were small, so you could just about shape your own course work.

FERGUSON: Do you remember what any of them were about?

KWOLEK: Well, some of them were in the fields of biochemistry and physical/organic chemistry.

FERGUSON: What was your first assignment at Du Pont? Who did you work for?

KWOLEK: The first person that I worked with was Dr. Emerson [L.] Wittbecker.

FERGUSON: He was basically doing organic synthesis?

KWOLEK: At that time he was working on elastomeric polyamides. This work involved both the syntheses of intermediates and polymers.

FERGUSON: How long did you work for him?

KWOLEK: I worked with him for about a year, and then I worked with Dr. Emmette F. Izard. He was a very, very outstanding chemist. He is the inventor of "Dacron" polyester. The one thing that I shall always remember about him was that he could sit down and dictate a report which covered six months or a year of research work with almost no corrections.

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FERGUSON: I know that he received at least one major ACS award for his work on polyesters.

KWOLEK: Are you thinking of the [1953] Schoellkopf Medal (1)?

FERGUSON: Yes. There seemed to be some dispute or question about who had the basic patents on the "Dacron" and "Mylar" type materials.

KWOLEK: I am not aware of that. There were some English patents on polyesters.

FERGUSON: He did the basic polyethylene terephthalate polymerization work (2).

KWOLEK: That's right.

FERGUSON: Were you working with him at that time?

KWOLEK: No, that was done before I came to Du Pont.

FERGUSON: Your first publication was with Izard?

KWOLEK: Yes. We were making polyesters other than polyethylene terephthalate. We were looking for new classes of polyesters. I worked on the preparation of intermediates and also did some melt polymerization of esters. At that time, I published two papers (3). One was on the intermediates, which I did alone. The other one involved research work with Izard. He was an extraordinary person to work with, because he was so very active mentally. He had all kinds of problem-solving ideas, and generated them daily. In addition, he had many outside interests. When we were transferred to Wilmington in 1950, he chose to transfer into the Film Department so that he could remain in Buffalo. I don't really know how many years he worked after we were transferred. I heard a number of years later that he was seriously ill. I believe he finally died about a year or two ago. I remember him with great admiration.

FERGUSON: When you worked with Wittbecker and Izard, did they give you assignments?

KWOLEK: I was generally given a broad assignment together with objectives. Usually, this involved the preparation of intermediates and polymers together with determination of some physical properties of both. At that time I did no spinning. I worked with Izard for about two years. I was then transferred to Paul [W.] Morgan's group, where I worked with cellulose derivatives, films thereof, and dyes.

FERGUSON: Did you have any particular background in organic synthesis before you started there?

KWOLEK: I took some advanced organic chemistry courses. I would say that I had about three years of synthesis experience before I started to work at Du Pont.

FERGUSON: Were you able to go into the lab and take over?

KWOLEK: None of us took over immediately. In those years polymer chemistry was not taught in schools. We had to learn a lot of chemistry in a hurry on the job. I had a great deal of freedom. We all did, as a matter of fact. The year that I joined the company, a lot of young people were hired, both men and women. The men, as far as I can remember, all had Ph.D. degrees, except for a few engineers. The women had bachelor's, master's, or Ph.D. degrees. Generally, the women went into analytical chemistry or into some form of physical chemistry. It was very enjoyable for all of us to come in at the same time, because we were all about the same age and single. So there was a very active social life in addition to very interesting and challenging chemistry in the laboratory. [laughter]

FERGUSON: Could you describe Buffalo during the time you were there?

KWOLEK: Buffalo was a very attractive, large city with many facilities for shopping, entertainment, education, etc. The low salaries we received limited our activities and determined our standard of living. Nowadays newly-hired Ph.D. students can afford luxury apartments and some even buy houses. But at that time, about all one could afford was a room in a rooming house or an apartment shared by several people.

FERGUSON: Was that bachelor's degree pay?

KWOLEK: Yes, the same also applied to Ph.D.'s.

FERGUSON: Do you remember what the starting salary was?

KWOLEK: My salary was $240 a month. Paul Morgan, who had a Ph.D. and who was employed several years before me, told me he had started at $125 a month. I remember that rent for my room was 30% of my salary. I calculated what people nowadays pay--say, a Ph.D. who has just come out of school--and it amounts to about 13% of his salary. Since we lived in rooming houses, we

met and had dinner, lunch or breakfast together in the various restaurants that were located in our area. We also enjoyed ethnic foods in East Buffalo restaurants. We spent many of our weekends at an old farmhouse, which was located near one of the Finger Lakes. It was owned by the parents of one of the engineers who was hired at about the same time as I was. We cooked our meals and had a great time.

FERGUSON: This was your weekend entertainment?

KWOLEK: That's right, that was our weekend. We hiked, swam, sailed, skied, ice-skated and square-danced. We also rented cabins in the Allegheny Mountains. I have many pictures of these weekends. It was a motley group of people. There was an understood agreement that there would be no pairing off on these weekends. Eventually, a number of marriages occurred among these people.

FERGUSON: So, your social circle was pretty much people who worked at the Yerkes lab?

KWOLEK: Well, no, not just that. There were friends that I made at church. It wasn't just the Catholic church, but also a Presbyterian church in the neighborhood. I made friends at both churches, and, of course, engaged in social activities at both churches. Then there was Kleinhans Music Hall, which was in the neighborhood. There were a lot of concerts. There were a lot of parks in the area that you could either walk to or take a bus. There was the Niagara River for boating. We also made friends with people who had cottages on the lake on the Canadian side, and so we would go there to swim and to picnic. It was a time of clean, healthy and very enjoyable social activity.

FERGUSON: How well was the laboratory equipped?

KWOLEK: I would say that, certainly for the time, it was very well equipped. There was money for equipment. Much of the very sophisticated equipment that we now have was not in existence then. What we needed, we had.

FERGUSON: My wife, Angela, came about 1948 or 1949, so she was there before you moved out.

KWOLEK: Yes, that's right.

FERGUSON: Pioneering Research Laboratory moved down to Wilmington about mid-1950?

KWOLEK: I would say mid-1950, yes.

FERGUSON: Did you find that a big change?

KWOLEK: It was a sad and uncertain time for me.

FERGUSON: Really?

KWOLEK: I delayed coming down as long as possible. I was considering marriage at the time, and the move forced me to make a decision that I was not ready to make. After much thought I decided to transfer to Wilmington. I left a large city with much activity and came to a very small town that was very provincial. For years, I attended art galleries and concerts and shopped in Philadelphia. It took a long while before Wilmington grew and developed into an interesting place to live.

FERGUSON: I had the impression that the Pioneering Research Lab group was pretty clannish. Maybe it was partly because most of you were strangers to Wilmington. I wouldn't say you were exclusive, but you tended to stick pretty close together, at least for a while.

KWOLEK: Well, I don't think we were deliberately clannish. First of all, many of us had been friends for a number of years and so it was very easy to remain friends. We didn't have to go out and make new friends, not immediately anyway. Also, we felt that there wasn't enough to do in Wilmington. This is one reason why we rented a cottage at the beach where we could escape on weekends. For me it was a tremendous cultural shock leaving Buffalo, New York, for Wilmington, Delaware, in 1950.

FERGUSON: That's interesting. When I interviewed at Buffalo, coming from Boston, I really thought that was the boondocks.

KWOLEK: It's all relative. It depends on where you are coming from. [laughter]

FERGUSON: I hadn't realized that it had that much to offer. I guess I missed that part of the tour. Let me ask here what you consider to be your most significant contributions.

KWOLEK: Well, I think the first would be the discovery of liquid crystalline solutions of synthetic aromatic polyamides and of fibers from these solutions. These fibers have exceptionally high tensile strength and stiffness combined with light weight. This discovery resulted in the development of "Kevlar" aramid fiber.

Number two would be the discovery and development with others in the laboratory of low-temperature polymerization processes for preparing aromatic polyamides and other condensation polymers. These polymers either did not melt, or else degraded before they melted. Until this time, the only known method for preparing these polymers was by melt polymerization. When we discovered the various low-temperature methods of polymerization, we opened up the entire field of intractable polymers.

FERGUSON: Was this condensation polymerization?

KWOLEK: These were condensation polymerizations and included interfacial, solution and modifications of each. Prior to this time, we had melt polymerization, which required intermediates that melted at reasonable temperatures, without degradation. Now we could use intermediates to prepare polymers that did not melt, say, at 300, 400, 500° Celsius or even higher.

FERGUSON: Did any of these result in commercial fibers?

KWOLEK: This work served as the basis for the future large-scale preparation of "Lycra" spandex fiber, "Kapton" polyimide film, and "Nomex" and "Kevlar" aramid fibers.

FERGUSON: Was this work done with Paul Morgan?

KWOLEK: This work was initiated about 1950 by Emerson Wittbecker, who made a polyurethane by a low-temperature method (4). However, prior to this time there was a German patent on the preparation of polyurethanes by a low-temperature condensation method. Paul Morgan and I got into this field of study and proceeded to make polyamides, polysulfones, polyesters, polyureas, and polyurethanes over a period of time. There were at least six to eight classes of different polymers, both homo- and copolymers, that we were able to make by these low-temperature methods. Other chemists in the laboratory also made important contributions to this field as evident by the patents. Now we were able to make hundreds of polymers that could not be made before.

FERGUSON: I suspect your best-known paper is the nylon rope trick (5). Do you agree? [laughter]

KWOLEK: Yes. I believe we have given out thousands of reprints of the nylon rope trick. Not only that, we have also given out countless bottles of solutions of the intermediates for the polymerization.

FERGUSON: Are you still doing that?

KWOLEK: We are still giving out the reprints. Our younger people are now demonstrating the nylon rope trick in both grade schools and high schools. Du Pont still demonstrates the nylon rope trick to its customers in the fiber field and at product exhibits. The nylon rope trick is on exhibit at the Smithsonian Institution and will be for a number of years. The nylon rope trick also has been taught to science teachers who come to seminars at the Du Pont Experimental Station.

FERGUSON: That must have gotten to be a real nuisance over the years.

KWOLEK: Well, it really wasn't that bad, because I had a technician who made up the solutions. [laughter] For me it's not bad. Now, if I had to do it myself, it would be a nuisance.

FERGUSON: Have you done any of these demonstrations yourself?

KWOLEK: I used to do them myself, possibly up to ten or fifteen years ago. I'm too busy now with other things, giving talks and preparing manuscripts.

FERGUSON: As I recall, it [the nylon rope trick] was a central attraction of the Du Pont exhibit at the New York World's Fair in the 1960s.

KWOLEK: I do remember that it was done there, but I don't remember what year it was.

FERGUSON: We went, but we could never get tickets to the Du Pont exhibit because it was so popular.

KWOLEK: I am not surprised.

FERGUSON: What were the rewards or lack of rewards for your accomplishments over the years? Your [1980] Creative Invention Award by the ACS is well known, and so were your other outside awards. I was thinking more in terms of your advancement and your treatment at Du Pont. Were your abilities and your work recognized?

KWOLEK: Well, let me see. I am probably recognized more by the outside world than by the Du Pont company. [laughter] These people are very familiar with my work through my patents and publications. You would be surprised at the number of telephone calls I get regarding my work even though I am retired.

FERGUSON: You were promoted to Research Chemist in 1959--that's thirteen years after starting.

KWOLEK: Then I became Senior Research Chemist.

FERGUSON: Senior Research Chemist in 1967, which was another eight years, and then Research Associate in 1974.

KWOLEK: That's right. Women of my generation had great difficulty in being promoted in the Du Pont Company, and especially in the Textile Fibers Department. In the case of the latter, we attributed it partly to the southern syndrome. When I asked whether a Ph.D. degree in chemistry would help me to advance in the company, I was told that it would not. I remember in the late 1940s, Ph.D. women stayed about two years before seeking employment elsewhere. Of course, during that time and even later, women chemists from other companies, as well, were returning to school to study for "women's professions."

FERGUSON: I was leading you into that. On the other hand, I think it is unusual for a B.S. chemist to attain research associate level. Do you know of others who have done so?

KWOLEK: I do not think it is unusual for a B.S. chemist to be promoted to a research associate. I know of several B.S. engineers who became vice presidents and even president of the Du Pont Company. One should be rewarded for his accomplishments regardless of degree.

Most B.S. chemists leave research for marketing, customer service or other fields because of the limited opportunity for advancement in research. My problem was that I loved research; I really found it fascinating. Every day was a challenge; every day, I learned something new. I think the excitement of research

was responsible for my changing my mind about going to medical school. At one point, I did have the money to return to school; but after weighing all the factors, I decided to stay on.

FERGUSON: Was this early in your career at Du Pont?

KWOLEK: This was in the late 1950s. It was a very exciting time at the laboratory. I realized at the time that because I had only a bachelor's degree, it would not be easy, that there would be prejudice, not only because of the fact that I had a bachelor's degree, but especially because I was a woman. I decided that I would get my compensation from writing scientific papers, giving talks and doing quality research.

FERGUSON: Were you encouraged to do that, or was that an uphill battle also?

KWOLEK: Well, writing a paper has always been an uphill battle, because everybody is very apprehensive that you will release information that might be useful to a competitor. It's an uphill battle not only for me, but for any industrial chemist. As a result, you frequently don't get a paper out until years after you did the work. It's the same problem, even now.

FERGUSON: I always felt that Textile Fibers was particularly secretive, even within Du Pont. In fact, it's a case in point that I didn't know until about the time you got your Creative Invention Award how deeply involved you were in the liquid crystalline polymer work. In fact, there was a "need to know" lid on many Textile Fibers Department reports. You had to get permission from a laboratory director to see such a report.

KWOLEK: Well, the work was considered to be a very important discovery from the beginning, from the very day that the liquid crystalline polymer solution was spun into oriented fibers with high tenacity and high modulus numbers.

[END OF TAPE, SIDE 2]

KWOLEK: There was an immediate realization that this discovery had great potential.

FERGUSON: Did you recognize it? What about the others in the laboratory?

KWOLEK: I recognized it, and it was recognized, as well, by others in the laboratory.

FERGUSON: What was it, the high tensile properties of the fiber?

KWOLEK: It was the great stiffness and strength combined with the high orientation of the as-extruded fiber. At that time, we were familiar with initial modulus numbers of 44 to 100 dN/tex for drawn "Dacron" polyester fiber. The very first fiber that I spun had a modulus of 380 dN/tex and a tenacity of about 5 dN/tex. In addition, I was able to spin a solution that was unlike any polymer solution that had ever been spun at the laboratory. It was thin and hazy and looked like a dispersion. When I tried to get the technician to spin it, he refused. He said that it was not spinnable, because it was too fluid, like water. Prior to this time, the standard isotropic solutions of polymers had considerable viscosity. In addition, the solution appeared to be very structured. It exhibited Schlieren lines, stir-opalescence and birefringence. It was very obvious that these solutions were unlike any of the other solutions that we had seen before.

FERGUSON: When did you recognize this as being liquid crystalline behavior?

KWOLEK: It wasn't until sometime later. I don't remember exactly, but at the time, I was not thinking of liquid crystals. Actually, I believe it was a co-worker, Paul Antal, who first recognized these solutions as being liquid crystalline.

FERGUSON: This was not a planned discovery?

KWOLEK: Oh, definitely not.

FERGUSON: Nobody was thinking that if you would make a polymer with a sufficiently linear and rigid structure, it should align well?

KWOLEK: When I started working in this field in 1964, I had been synthesizing a variety of aromatic polyamides. These were primarily meta-oriented or mixtures of meta- and para-. "Nomex" aramid fiber, which is meta-oriented, had modulus numbers of 100 or somewhat greater. At that time, we considered these polyamides to be quite intractable. Then we began to think about new fields to conquer. The polymers of choice were the rigid-

chain, para-oriented aromatic polyamides. We expected them to be somewhat stiffer than "Nomex" fiber but we never expected liquid crystallinity.

FERGUSON: I have a Du Pont photograph here that identifies the discovery team [see next page]. It includes (from left to right) you, Herbert Blades, Paul Morgan, and Joseph L. Rivers, Jr. How did you apportion credit? Who did what?

KWOLEK: Well, I made the initial discoveries of the liquid crystalline solutions of synthetic aromatic polyamides, and high tenacity and high modulus fibers therefrom. With the realization that there was commercial potential here, we decided to cover the field of rigid-chain aromatic polyamides as fast as possible. Initially, I worked with both poly(1,4-benzamide) and poly(1,4-phenyleneterephthalamide). Later, I was assigned to work primarily on the development of poly(1,4-benzamide) for commercialization. Morgan worked primarily on patenting the discoveries. He and Tom [Thomas I.] Bair took over the preparation and spinning of poly(p-phenyleneterephthalamide). Then, Joe Rivers was assigned to work on end-use applications. He made the first composites of poly(1,4-benzamide) shortly after I spun the fiber. I still have the bars. Herb Blades got into the picture a little later, when he used air-gap wet spinning for the higher concentration poly(p-phenyleneterephthalamide)/ sulfuric acid solutions. This procedure gave the higher tenacity fibers directly on spinning. With his method, if you heat-treated the fiber, the tenacity did not further increase; but the modulus and crystallinity did. Now, with poly(1,4-benzamide), that I had worked on, and with poly(para-phenyleneterephthalamide) that Morgan and Bair worked on, the initial as-spun tenacities were lower; but on heat treatment, tenacities, initial moduli and crystallinity increased. This was how the work was divided.

FERGUSON: I see.

KWOLEK: Then, of course, other people got into the act. People who were assigned to work on co-polymers and other rigid chain polymers. It was a very complex venture, with people working on polymers, process and end-use applications.

FERGUSON: I've seen your patent. It's a big, thick thing with many claims. Is your patent basically on the composition of matter?

KWOLEK: I have two. One is on composition of matter and the other is on liquid crystalline solutions of aromatic polyamides (6).

FERGUSON: Can you say a little bit about the suits going on? There's one coming up in federal court now with AKZO [N.V.] (7).

KWOLEK: The first suit, with the International Trade Commission, was in Washington, D.C. It was decided in our favor (8).

FERGUSON: Can you back up a little bit? I'm aware of AKZO and all the litigation before the Dutch Patent Senate. Were you involved in that?

KWOLEK: I don't understand what you're saying.

FERGUSON: The issue was whether the Du Pont or AKZO patents would be allowed in the Netherlands.

KWOLEK: Well, so far only the AKZO patents have been allowed in the Netherlands. Of course, we consider AKZO to have infringed on our patents. This is why we are fighting to keep them from selling their product here in the United States, as well as elsewhere (9).

FERGUSON: Well, I can't ask for your prognosis on what's going to happen. It must have been a bit of a jolt to find that somebody else was disputing the Du Pont patents. Do you know anything about the timing of the AKZO discoveries versus yours?

KWOLEK: No, I don't. I have been involved only in depositions concerning my work. I have no idea when they started their work, or exactly what they have done.

FERGUSON: Does the dispute involve the solvent systems?

KWOLEK: It involves everything. We consider them to have infringed on our product.

FERGUSON: There's a lot of money involved there, I guess.

KWOLEK: We have spent many millions of dollars on the development of "Kevlar." In view of the tremendous amount of money that we have put into both research and development, I would hate to think that anything might happen whereby we would be unprotected. If our patents can't protect our discoveries, it just seems to me that our patent system doesn't amount to much.

FERGUSON: You're not the first that I've heard that from. Have there been problems with any of your other patents?

KWOLEK: This is the first one. I guess, you know--and I'm not talking just about myself--that when you make a commercial discovery, litigation frequently follows, because other companies try to get into the field. They read your patents and look for loopholes. It gets to be very messy.

FERGUSON: Do you have anything else you want to add about your discoveries?

KWOLEK: I have obtained much satisfaction from my discoveries because they have resulted in products which have been of benefit to mankind. In addition, they have been basic enough to have added to the knowledge of polymer chemistry. I can look back on my work and feel good. I'm always surprised to hear from scientists around the world who tell me that they are familiar with my work and admire it. I can only conclude that I made the right move when I decided to stay with chemistry.

FERGUSON: Have you had any desire to go into the management line?

KWOLEK: No, I have never had any desire to be involved in the management line of work. I really think I'm too soft for something like that. I have difficulty in telling someone that his work isn't satisfactory. I have found it rather painful when I have had to do so. I like work that is highly creative. As far back as I can remember, I have always been involved in creative activity. I like writing, and I hope one of these days to do some, particularly after I'm retired.

FERGUSON: For many years, Paul Morgan was your supervisor.

KWOLEK: Yes. Actually, he had many position titles while I was in his research group.

FERGUSON: Did he continue to work in the lab?

KWOLEK: Paul maintained a laboratory and the amount of his direct involvement varied from time to time. He had a technician who carried out his assignments. Paul spent much time writing--a book and scientific publications (10). He did like to experiment in the laboratory and he was very good at it.

FERGUSON: Textile Fibers gave him free rein to write at work?

KWOLEK: That's right.

FERGUSON: Not everybody had that privilege. I guess if you get senior status?

KWOLEK: Well, he had senior status.

FERGUSON: Then you worked pretty independently of Paul?

KWOLEK: Oh, yes.

FERGUSON: Always, or just in the recent years?

KWOLEK: I would say probably from the day that I came down to Wilmington in 1950, I worked independently of him but in his research group.

FERGUSON: You coauthored a lot of papers with him (11).

KWOLEK: Oh, yes, because frequently we were working on related things.

FERGUSON: Did you have supervisors after Paul?

KWOLEK: I had other supervisors and managers before and after Paul. I like to work independently but I enjoyed my contacts with all of them.

FERGUSON: Did you have a report-writing schedule?

KWOLEK: We were supposed to write two reports a year.

FERGUSON: Did you have other special summaries or reports?

KWOLEK: There were monthly reports that were required. There could be more frequent reports, even weekly, if you were working on a "hot" project. Sometimes, it was difficult to find something worthwhile to write about.

FERGUSON: I've had that experience. How was information really passed up the management ladder in Textile Fibers?

KWOLEK: Well, you could write a memo. You could also pass the information orally to the supervisor, who in turn informed the manager and the lab director. Or, you could go directly to the manager or lab director, depending on how important the information was. When I first spun the liquid crystalline poly(1,4-benzamide) solution into the very high modulus and tenacity fibers, I remember telling Paul [Morgan] and the laboratory director directly.

FERGUSON: And that was George [Frank] Lanzl?

KWOLEK: No, that was John Griffing.

FERGUSON: Was there any skepticism?

KWOLEK: Initially, there was on my part. I had the tenacity and initial modulus measurements redone at least three times before I accepted the numbers.

FERGUSON: That was before you decided to report the results?

KWOLEK: That's right. I did not want to make an incorrect report that I would then have to retract. It would have been rather embarrassing, so I had the numbers checked several times.

FERGUSON: Did that little report shoot right up to the top in a hurry?

KWOLEK: I'm sure it did. [laughter] John Griffing certainly remembered it. He told me that he remembered how terribly excited I was, and he was, too.

FERGUSON: I'd like to ask you about some of the people you worked with, and about your philosophical feelings about your career and about women in industry. You mentioned Izard. What about Emerson Wittbecker? You've known him for many years.

KWOLEK: Well, I have known him, but as I said, I only worked with him for about a year at the very beginning of my career. Many years later I worked with him again for a very short period just prior to his retirement. He was a competent scientist.

FERGUSON: Paul Morgan, of course, is your mentor and colleague.

KWOLEK: My mentor and colleague, that's right. Actually, we're still writing papers together. He retired in 1977, but I frequently see him. Right now, we're putting a paper together on polyazomethines (12). It makes it very nice because I still have the laboratory facilities at my disposal. [laughter]

FERGUSON: So you're still doing research to put in your papers.

KWOLEK: Exactly. I'm filling in missing information and adding new information to improve the quality of the paper.

FERGUSON: You still have unpublished work that you could write up?

KWOLEK: Yes, that's right. Several papers, in fact.

FERGUSON: If you could find time?

KWOLEK: Oh, yes. Precious time. As a matter of fact, John [R.] Schaefgen, Paul Morgan, and I just completed an encyclopedia article on liquid crystalline polymers (13). It was a painful, thankless job. I'll never do it again.

FERGUSON: I have a terrible time finishing old papers. How do you manage that? Did you have good write-ups or can you just go back to your old reports?

KWOLEK: The encyclopedia article required a tremendous amount of searching for pertinent material. The computer helped with abstracts, but we had to read or scan many selected patents, articles, and books.

As far as writing papers on original work, I have been helped by detailed records of my work both in my notebooks and in progress reports. Even with good records, writing a paper while conducting a research project can be a chore. But somehow it

gets done, if you are willing to sacrifice some of your evening and weekend hours. Morgan and I are now writing a paper on polyazomethines. I recently gave a talk at the University of Akron [Polymer Processing Hall of Fame Award, November 1985], and I am planning to write a paper for the IUPAC [International Union of Pure and Applied Chemistry] meeting in Jerusalem in August of 1987. By then, I expect to be retired, but I will still go to that meeting to give the paper.

FERGUSON: I remember that when we were riding in a car pool together, you were always carrying home journals to read. It was never a forty-hour workweek?

KWOLEK: I rarely have a forty-hour workweek. I can't write papers, do bench research work, write reports, attend meetings, keep up with the literature, etc., all in an eight-hour day. So I read and write at home as necessary.

FERGUSON: Were you given pretty good freedom to go to scientific meetings?

KWOLEK: Definitely. I had no problems there. I went to Paul Flory's 75th birthday party. In May I went to a meeting in England.

FERGUSON: Was it always that way, or only after you got a reputation?

KWOLEK: In the early days we were limited to one trip per year east of the Mississippi. This sounds very funny considering that in later years even new chemists could go to several meetings at any location depending on need.

FERGUSON: You mentioned Hale Charch earlier. You said he was eccentric--I would agree with that. Was he an inspiring leader?

KWOLEK: Yes, I would definitely say so. He was a very imaginative, inspiring and caring person. He wandered around the lab and talked to all the employees. He was always interested in what the research people were doing at the bench. This one-on-one exchange of ideas certainly inspired the technical employees.

FERGUSON: Any other particularly outstanding people that you worked with?

KWOLEK: Well, there was Paul Flory. I enjoyed talking with him very much. I think he was about the most brilliant man that I have ever known. In addition, he was a very caring person, very much interested in other people. I don't believe that I ever consulted with him that I didn't leave inspired. Of all the scientists I have known in my life, I probably admired him the most.

FERGUSON: What was his reaction to the liquid crystalline discovery?

KWOLEK: He was very pleased and somewhat surprised. As you know, in 1956 Flory published a theoretical examination of the behavior of monodisperse rigid rod polymers in solution and the conditions under which they would form anisotropic phases (14). He now mentioned expanding the theory of polymer liquid crystals and proceeded to do so. I felt a great loss when he died. More recently, Peter [A.] Irvine and Bob [Robert R., Jr.] Matheson, who were Flory's students, have continued this theoretical study of liquid crystalline polymers.

[END OF TAPE, SIDE 3]

KWOLEK: Another person that I knew fairly well was Herman Mark. He was a Du Pont consultant when I worked at the Yerkes Lab in Buffalo, New York, and then to a lesser extent in Wilmington. I still see him on occasion at meetings. He remains the delightful and charming gentleman from Vienna. [laughter]

FERGUSON: It must be because you're a woman--he always ignores me. Did he ever introduce you to his girlfriend?

KWOLEK: No, I haven't met his girlfriend, but he still kisses women's hands, even at the age of ninety or so. [laughter]

FERGUSON: I was told to be careful about what I said to Mark. Did you discuss your work with him freely?

KWOLEK: While I worked in Buffalo I did, but not after moving to Wilmington. Mark travels a great deal and talks to many people. He loves to exchange information. Since much of our work was of a patentable nature, we had to be very discreet.

FERGUSON: He was a great disseminator of information. I can remember his favorite lecture title was, "What's New in Polymers in Europe," or something like, "Recent Developments in Polymers in

Europe." In fact, I think that's the only lecture title he ever used for many years.

KWOLEK: That's right. I'm sure he went to Europe and told them what was new in America--and so it went around and around.

FERGUSON: Was he an inspiring person?

KWOLEK: He was a very enthusiastic person. He's called the Father of Polymer Chemistry, but I do not place him on the same level as Paul Flory.

FERGUSON: How about other consultants? I'm thinking of physical chemists, particularly.

KWOLEK: Well, if they were strictly physical chemists, I probably did not have a great deal to do with them, since my work was primarily of an organic nature.

FERGUSON: Did Speed [Carl S.] Marvel consult much?

KWOLEK: Oh, yes. I know Speed Marvel very well, and I consulted with him for many, many years. He contributed a great deal to the field of polymer chemistry. He certainly had a tremendous amount of experience and until recent years, he could remember everything he had read from many years back. He is certainly a person that I admire very much for his technical ability, and, on the side, for his ability to recognize thousands of birds by appearance, flight pattern and song.

FERGUSON: Are there any other colleagues that you worked with in Textile Fibers or Du Pont that are memorable?

KWOLEK: Well, certainly Paul Morgan.

FERGUSON: Yes, we've touched on Paul.

KWOLEK: That's right; I consider Paul to be an extremely capable and outstanding chemist.

FERGUSON: Herb Blades? He's an outstanding polymer physicist or physical chemist?

KWOLEK: I think Herb is a physical chemist, but I am not sure. Among his many talents, Herb is especially good at designing and constructing processing equipment for unique products. This is also evident in his patents.

FERGUSON: You already indicated that you would do it all over again.

KWOLEK: I would do it over again, yes.

FERGUSON: Do you give any special advice to your younger female colleagues, or the new people coming in?

KWOLEK: Well, I have advised younger women that total equality is still a long way down the pike, probably another generation or two. But no matter what, you have to do top quality work and actively pursue any opportunities for advancement and self-development.

FERGUSON: Do you feel that there is still a salary differential?

KWOLEK: There certainly is not a salary differential at the beginning, but the fact that men are promoted more frequently than women means that eventually there is a salary differential. There are different ways of doing it.

FERGUSON: Does the Du Pont Bonus Plan really work?

KWOLEK: Well, I certainly have received bonuses. The bonus plan is very secretive, so you never really know who received a bonus and what the amount was. It is impossible to say how fair it is.

FERGUSON: Do you feel comfortable financially now? Has the "Kevlar" discovery made your day?

KWOLEK: The "Kevlar" discovery has not made my day. It takes a lifetime of saving to assure a fairly comfortable old age, particularly if you start out at a salary of $240 per month and you progress at the rate that women of my generation did.

FERGUSON: The usual stories go around that so-and-so invented "Kevlar" and they got huge bonuses.

KWOLEK: Well, I certainly did not receive a huge bonus, and any amount that was received was greatly diminished by federal and state income taxes. Furthermore, it was many, many years before "Kevlar" began to turn a profit, and bonuses are dependent on profits. At that time "Kevlar" was not making a profit.

FERGUSON: I'd always figured that bonus money gets divided up in a lot of different ways.

KWOLEK: Well, that's right. It wasn't just I who got a bonus. Although I made the initial discoveries, many people contributed to the development of "Kevlar." They also were awarded a bonus.

FERGUSON: What about the future? Would you still like to be active in some way in science when you retire?

KWOLEK: Well, I'm thinking of retiring. I'm certainly planning on consulting. I'm planning on writing, and I'm planning on doing some things for myself, for a change.

FERGUSON: Well, I've got bad news for you. I'm busier now in retirement than I ever was. It seems to me that I have less time now, but I don't want to discourage you.

KWOLEK: [laughter] No, don't discourage me.

FERGUSON: Thank you again, Stephanie. Is there anything else you want to add?

KWOLEK: I don't think there's anything else at the moment. I'll probably think of something afterwards.

FERGUSON: I have an additional thought. Have you seen a change in professionalism (for better or worse) over the years since you've been involved in chemistry and polymers?

KWOLEK: Well, it's hard to say, because the entire American industry is going through a transition. Profits in textile fibers have declined and there has been a great increase in foreign competition where labor is cheap. There is a much better future for industrial and specialty fibers and for applications related to these fibers.

For the polymer/fibers industry it means the elimination of

non-profit-making polymers and fibers, and therefore a reduction in personnel. Future chemists will have to be very adaptable. There may not be the former employee allegiance and there may be a reduction in discoveries resulting from long-term research.

FERGUSON: Do you see other parts of the profession that look good to you in the future?

KWOLEK: Well, I still like polymers. There's still a lot of potential here for products that should be of benefit to humanity. Of course, everybody's interested in life sciences right now, but it may take a long time before that field becomes profitable. Agricultural chemicals are still profitable.

FERGUSON: Well, I guess that's a complaint of polymers in general--that so many of them have gotten to be commodities. Du Pont has never really done well in those areas.

KWOLEK: Du Pont has done well in nylon. We now have to come up with a few more major discoveries. I don't mean just little things, but big things that will revolutionize the industry.

FERGUSON: You never got involved with the non-wovens and spun-bonded products, did you?

KWOLEK: No, I haven't. Generally people who were more interested in product development got into that field, whereas I have been more interested in syntheses of new polymers, films and fibers, new processes, and new intermediates.

FERGUSON: Are you going to be testifying in the federal court suit, or is it mostly by deposition?

KWOLEK: Well, I think I will be involved in the coming case in London, which starts sometime in June of this year. At least, at the present time, I expect to be testifying. Actually, I was supposed to testify here in Wilmington last December, but that case was delayed until January of 1987.

FERGUSON: Goodness.

KWOLEK: It goes on forever and ever.

FERGUSON: Are you going to continue working at Du Pont while this

goes on, or do you think you'll retire earlier than that?

KWOLEK: I know I'm going to retire, possibly at the end of this year. But I expect to work as a consultant.

FERGUSON: Are there any further additions?

KWOLEK: On reflection, I realized that I gave some incorrect values for the first liquid crystalline polyamide fiber that I prepared and I would like to correct these now. These poly(1,4,-benzamide) fibers had a breaking tenacity of about 6 grams per denier, and a modulus or stiffness of about 430 grams per denier. For comparison, glass fibers have a modulus of about 300 grams per denier.

FERGUSON: Thank you again, Stephanie, for having given us the time for this interview.

[END OF TAPE, SIDE 4]

NOTES

1. See "Scientific Success Story of Polyethylene Terephthalate," Chemical & Engineering News, 32 (1954): 3724-3728.

2. E. F. Izard, "Production of Polyethylene Terephthalate," U.S. Patent 2,534,028, issued 12 December 1950 (application filed 13 May 1948); E. F. Izard and Lawrence A. Auspos, "Polyethylene Terephthalate High-Molecular Polymerization Products," U.S. Patent 2,597,643, issued 20 May 1952 (application filed 31 October 1947).

3. E. F. Izard and S. L. Kwolek, "Reaction of Perfluoroalkyl Chlorides with Silicon," Journal of the American Chemical Society, 73 (1951): 1156-1158; Izard and Kwolek, "Esters of p-Carboxyphenoxyalkaloic Acids," Journal of the American Chemical Society, 73 (1951): 1861-1862.

4. Emerson L. Wittbecker, "Polyurethanes from Piperazines," U.S. Patents 2,731,445 and 2,731,446, issued 17 January 1956 (applications filed 30 March 1953).

5. P. W. Morgan and S. L. Kwolek, "The Nylon Rope Trick-Apparatus for Continuous Polymerization," Journal of Chemical Education, 36 (1959): 530; Morgan and Kwolek, "The Nylon Rope Trick. Demonstration of Condensation Polymerization," Journal of Chemical Education, 36 (1959): 182-184.

6. S. L. Kwolek, "Optically Anisotropic Aromatic Polyamide Dopes," U.S. Patent 3,671,542, issued 20 June 1972 (application filed 23 May 1969); S. L. Kwolek, "Wholly Aromatic Carbocyclic Polycarbonamide Fiber Having Orientation Angle of Less Than About 45°," U.S. Patent 3,819,587, issued 25 June 1974 (application filed 7 September 1971).

7. See "Du Pont to Defend Kevlar Use," New York Times, 21 April 1986, Business and Finance section; and "The Fight Over Fiber Patents," Chemical Week, (7 May 1986): 10.

8. See "ITC Ruling Favors Du Pont in Aramid Fiber Dispute," Chemical Week, (22 May 1985): 16.

9. See "For AKZO: No U.S. Imports of Aramid Fibers," Chemical Week, (5 February 1986): 5; and "Court Upholds Du Pont Aramid Patent," Chemical & Engineering News, (5 January 1987): 13.

10. Paul W. Morgan, Condensation Polymers: By Interfacial and Solution Methods (New York: Interscience Publishers, 1965). Additional information on Paul Morgan may be found in the Beckman Center Oral History File #0033.

11. A complete list of the publications of Stephanie Kwolek may be found in the Beckman Center Oral History File #0028.

12. P. W. Morgan, S. L. Kwolek and T. C. Pletcher, "Aromatic Azomethine Polymers and Fibers," Macromolecules, 20 (1987): 729-739.

13. S. L. Kwolek, P. W. Morgan and J. R. Schaefgen, "Liquid Crystalline Polymers," in H. F. Mark, N. M. Bikales, C. G. Overberger, G. Menges and J. I. Kroschwitz, eds., Encyclopedia of Polymer Science and Engineering, vol. 9, 2nd ed. (New York, New York: John Wiley & Sons, 1987): 1-61.

14. P. J. Flory, "Phase Equilibriums in Solutions of Rodlike Particles," Proceedings of the Royal Society, A234 (1956): 73-89.

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