

HARRY S. MOSHER AND ARTHUR C. COPE, EARLY ORGANIC CHEMISTS WHO MENTORED WOMEN

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In his 1973 Cope Award address, Robert Burns Woodward jokingly referred to a target molecule as “bigboobsenone” (1). That such humor was acceptable “...reflects the fact that his chemical audiences even into the 1970’s were preponderantly male and such persiflage seemed still at times to be condoned (2).” Woodward, an acknowledged pioneer of American synthetic organic chemistry, had a single woman, Elga Wasserman, complete a Ph.D. in his group, and she subsequently left the field of chemistry (3). That Woodward was able to make such a crass remark in an award address indicates that the attitudes of at least some organic chemists have not been particularly welcoming to women.

The number of female scientists has increased in all of the disciplinary areas of chemistry, including the subdiscipline of organic chemistry (4). However, while female U. S. citizens represent 25% of the doctoral graduates in 2005 (5), none of the organic doctoral graduates from 2005 were women (6). Between 1997-2006, 13.7% of the Ph.D.s in organic chemistry were awarded to women (6). There are and have been organic chemists who support and mentor women. The history of such support has not been fully described or appreciated, even by women in the field.

Many areas of chemistry have prominent women who were early contributors. Female crystallographers can look to Kathleen Lonsdale, Dorothy Hodgkin, and Rosalind Franklin. Female radiochemists have Marie Curie and Irene Joliot-Curie. Biochemists acknowledge Icie Hoobler, Gerty Cori, and Gladys Emerson among

others. Organic chemistry has no acknowledged female “founding mothers,” although there were women making contributions in the field. Many of the accepted “founding fathers” of synthetic organic chemistry had few women in their research groups.

How chemists, male or female, of any subdiscipline are encouraged or supported has not been well documented. Examination of the memoirs of organic chemists can lend some insight into how this encouragement took place, both in terms of how they were encouraged and how they supported others. Hans T. Clarke describes working with women in industry during World War I (7):

In the summer of 1918, Mees charged me with the organization of a laboratory for the preparation of research organic chemicals to meet the urgent needs of universities, whose stocks had become depleted owing to the impossibility of securing supplies from Germany. As at that time almost all the relatively few American-trained organic chemists were actively employed in government service, the laboratory was staffed by young women, all recent college graduates who had majored in chemistry. These girls displayed immense enthusiasm, cooperativeness, and application, but in general were not well adapted to preparative work on a large laboratory scale; accidents were alarmingly frequent, and it proved impossible to assign more than two preparations to each girl for simultaneous operation. After the first year, therefore, replacements and additions to the group were made with men.

Egbert Havinga, an organic chemist at the University of Leiden from 1946-1979, describes working with women differently (8):

At the risk of being considered seriously biased, I would like to report that although only a small number of women choose to study organic chemistry, this in my experience is compensated by the excellent capacities of those few in both experimental research and theoretical exploration..

The male culture of synthetic organic chemistry has not gone unnoticed by all. Carl Djerassi noted in his autobiography (9):

...the American organic chemistry edifice has only two main pillars: physical organic chemistry, with major emphasis on mechanisms of organic reactions; and synthetic organic chemistry, which has become the overriding field in terms of attention and prestige. This includes both 'macho' syntheses of exceedingly complicated natural products and the development of new synthetic methods and reagents.

Female organic chemists may not have enjoyed any less support than in the other subdisciplines of chemistry. Yet, why do percentages of doctoral degrees earned by women in organic chemistry continue to lag behind compared to the overall chemistry Ph.D.s? Is it due to few female role models, overt or concealed sexism, a paucity of research groups where women are encouraged, or a combination of these elements? In 2006 less than one third of the earned doctorates went to female organic chemists, which is still significantly more than in the previous ten years (4, 6). In that same year almost half of the earned doctorates in biochemistry and analytical chemistry were awarded to women (4, 6).

The total percentage of women in the field of chemistry at all education levels was 7.0% in 1947, and in the subfield of organic synthesis in 1956-58, 4.73% of those employed full-time were women (10). While Woodward's research group graduated a single woman, other groups did include a few women. For example, William S. Johnson had a few female students and post-docs (14 of 339 co-workers), and he did acknowledge them as coauthors on his publications (17 of 269) (11). By the last ten years of Djerassi's active research career in the 1980s, about one third (29%) of his publications had female coauthors, although many of Djerassi's later publications could be considered to be biochemistry, an area ostensibly more welcome to women. While there were no women who were faculty members at Ph.D.-granting institutions in the early years of organic chemistry in the United States (10), there were men who supported women to become

top-flight researchers. Some of these men, notably John D. Roberts, describe their professional mentoring relationships with women in their memoirs (12).

The shortage of peer and mentor support for female organic chemists can only partially explain the current relative dearth of women in synthetic organic chemistry. As the role of the research advisor can be crucial (13), some male organic chemists have effectively and consistently mentored women, and high percentages of women were present in their research groups. Arthur C. Cope and Harry S. Mosher are two such organic chemists who valued the contributions of their female research colleagues. The time period of Cope's research was between 1934 and 1966, and Mosher maintained his research group from 1942 to 1980.

Backgrounds of Cope and Mosher

Arthur C. Cope earned his B.S. in chemistry from Butler University in 1929, and Harry S. Mosher completed a B.S. in chemistry from Willamette University in 1937. These two institutions were founded with remarkably similar missions. Butler was founded in 1855 on the audacious vision to provide interracial coeducation to aspiring students (14), and Willamette, founded in 1842, was one of the early coeducational institutions (15). Butler was the third school in the nation to award a bachelor's degree to a woman, and Willamette's first



Arthur C. Cope, courtesy MIT Museum

graduate was a woman. While it is doubtful that either man encouraged women because of the progressive traditions espoused by their undergraduate institutions, it is remarkable that their undergraduate experiences were at such similar institutions.

Both Cope and Mosher performed their graduate work at state schools, Cope at the University of Wisconsin and Mosher at Pennsylvania State University, with prominent organic chemists. Cope obtained his Ph.D. in organic chemistry under S. M. McElvain in 1932. Two women, Marguerite Kuehn and Mary E. Englert, were coauthors on McElvain's publications. It is possible that Cope may have overlapped with each of these researchers. Mosher earned his Ph.D. in 1942 under the direction of Frank C. Whitmore. Whitmore worked with four different women coauthors, Frances H. Hamilton, Gladys E. Woodward, Harriet A. Southgate, and his wife Marion Gertrude (Mason) Whitmore. There were two other women, Dorothy Quiggle and June Ruth Pfister, who worked in the research groups of collaborators who also appeared on Whitmore's publications. Women did not work in Whitmore's research group beyond 1934, before Mosher began his graduate work. Despite these apparently positive interactions with female co-workers, it appears that McElvain and Whitmore did not have any female researchers in later years. Mosher's brother, William A. Mosher, also earned his Ph.D. in organic chemistry with Whitmore and was chair of the Chemistry Department at the University of Delaware from 1946-1969. William published articles with only two women (Sylvia A. Farnum and Sally McNeill Lemke).

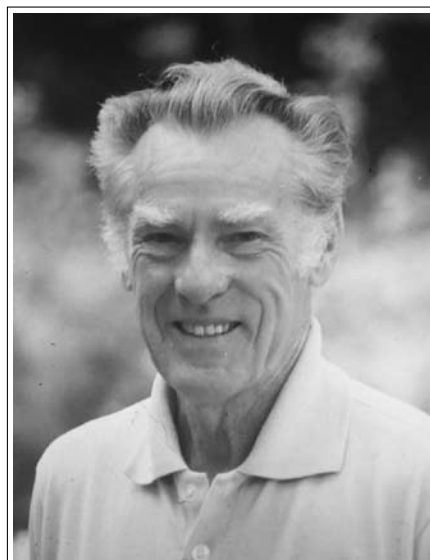
In addition to his training at Wisconsin, Cope was a National Research Council postdoctoral fellow at Harvard, where he worked with E. P. Kohler, who also had a few female colleagues. Kohler published papers with Gertrude L. Heritage and Marie Reimer as coauthors while teaching at Bryn Mawr College, an all women's school. In addition, Kohler published with Alice Graustein in 1922 after he moved to Harvard University (16).

In 1934 Cope took an appointment at Bryn Mawr College. Full-time positions were difficult to find at Ph.D.-granting institutions in the 1930s (17), and this appointment began as a temporary position. Cope's official biographies (18) only acknowledge two female graduate students as coauthors on most of his Bryn Mawr work. In fact, he worked with five female Ph.D. students and one laboratory demonstrator (or lecturer or research assistant, depending on the appointment for that year),

who was misidentified as a graduate student. He also worked extensively with undergraduate students, and eight of them became coauthors on publications. During his brief time at Bryn Mawr, from 1934-1941, Cope was able to amass a significant record of scholarly publication. This positive experience with female students at an all women's school likely made his laboratories welcome to women throughout his career.

As was common for the time, both Cope and Mosher contributed to the World War II effort through organic chemistry research, Cope at Columbia University (1941-1945) and Mosher at Penn. State (1942-1947) as an assistant professor. Each of them moved to their final institutions in the mid-1940s, Cope to the Massachusetts Institute of Technology in 1945, where he spent most of his career as department chair, and Mosher to Stanford University in 1947. At these schools, they were each supportive of all the researchers in their laboratories, undergraduates, graduate students, and postdoctoral fellows, regardless of gender.

Both Cope and Mosher are recognized for reagents or reactions named after them. Cope's research is not-



Harry S. Mosher
courtesy James D. Morrison

ed for the Cope Rearrangement and the Cope Elimination (19). As a research scientist, he authored or edited over 300 professional articles and patents. Mosher is most widely known for the chiral derivatizing agent that bears his name (20). As a research scientist, Mosher authored over 180 scholarly publications and patents. The American Chemical Society, either nationally or locally, has established awards in each man's name. Cope's life and work have been well documented (18). However, in addition to his named reactions, he is best known to contemporary organic chemists for the two awards that bear his name, administered by the American Chemical Society: the Arthur C. Cope Award and the

Arthur C. Cope Scholar Award (21). A brief biography of Mosher is available (22), and he has been honored with the Carol and Harry Mosher Award through the Santa Clara Valley Section of the American Chemical Society (23). Cope performed research with a total of 27 female researchers, and women were listed as coauthors on 55 of his scholarly articles. Mosher worked with 26 female researchers, and women are listed as coauthors on 57 of his publications.

At MIT, through the late 1960s, only about 2% of the undergraduate population was female (24). By 1963, when other coeducational institutions were awarding doctorates to women in the sciences at levels as high as 28%, MIT did not even make the list of the top 25 institutions for awarding doctorates to women, even though they were ranked fourth overall (10). By comparison, in 1963 Stanford was 19th on the list for awarding doctorates to women, while it was ranked 16th for awarding doctorates overall (10).

The Women

The women who passed through the Cope and Mosher laboratories are listed in Tables 1-3. Women who left these research groups were often able to continue work as chemists or in other areas of science, and many are still active chemists today.

During his years at Bryn Mawr College, Cope was able to establish relationships with pharmaceutical companies to support his research. He was able to secure research associate positions sponsored by Sharp and Dohme, through which he supported several women, the first being Evelyn Margaret Hancock. These sponsored associates continued through much of his career. Hancock earned her Ph.D. at the University of Illinois in 1936, and the demonstrator and research associate positions were her first professional positions. Hancock was supported by Sharp and Dohme in this manner through 1945.

Cope had connections with other pharmaceutical companies as well and was able to persuade these companies to hire his graduates into research positions. Dorothea (Heyl) Hoffman was the first female laboratory research scientist hired by Merck (25). She worked there until 1956, when she was married and was subsequently forced to leave the laboratory—a common practice at the time. After her career at Merck, Hoffman became a chemistry consultant and then a high school chemistry teacher. American Cyanamid, acquired by Wyeth in 1994, employed Corris Maybelle Hofmann (26),

Elizabeth MacGregor Hardy (27), and Mary Elizabeth Wright. Elizabeth Mary Osman worked in a variety of industrial and academic positions after earning her Ph.D. (28). Osman worked as a biochemist at Hercules Powder Co., Corn Products Reference Co., Michigan State University, the University of Illinois, and the University of Iowa. She was the first woman to be elected the chair of the Carbohydrate Division of the American Chemical Society (1966-67) (29).

Of the eight undergraduate women from Bryn Mawr College who worked with Cope, at least four of them continued in the sciences. Ruth Rogan earned a Ph.D. at the University of Chicago in 1949. Norma Finkelstein completed a Ph.D. in physiology at New York University. Kathryn Hoyle started graduate school at the University of Wisconsin, working with Homer Atkins. Esther Hardenbergh earned her Ph.D. in physiology from Harvard University in 1950.

Postdoctoral associates from Cope's years at MIT also went on to a variety of positions. Marion Burg became an instructor in chemistry at Queens College for two years before taking a permanent position at DuPont (30). Patricia Trumbull and Ruta Bly were given the opportunity to do research while their husbands were postdoctoral associates in Cope's laboratory. Bly continued research work with her husband. Elizabeth P. Burrows worked as a research associate at Oakland University and is currently working at the U. S. Army Biomedical Research & Development Laboratories at Ft. Detrick (31).

Cope's Ph.D. students from the MIT years were also successful in fields of education, chemistry, and the corporate environment. Emily Wick, the first woman tenured at MIT in 1963, was selected by the MIT president in 1965 to improve the quality and graduation rate of women in her position as Associate Dean of Student Affairs (24, 32). Phylis Moore was employed at Polaroid Corp. Mary Youngquist was an NIH predoctoral fellow while at MIT, one of few women at the time, and took a position with Eastman Kodak after a postdoctoral stint at the University of Minnesota (33). Beverly Pawson worked her way up to associate director of chemical research at Hoffman-La Roche after a postdoctoral position at the Mellon Institute (34).

In addition to his researchers, other women appeared on Mosher's publications. He coauthored a few publications with his wife, Carol Walker Mosher, a professional chemist (35). This was a temporary situation until she obtained a permanent position at SRI International.

Three women, Geraldine J. Fuhrman, Jane Fail Wakely, and Hanna S. H. Yuan, appear as coauthors on Mosher papers, as they worked in the research laboratories of collaborators (Fuhrman and Wakely in the laboratory of Fuhrman, Yuan in the laboratory of Robert Bau).

In addition to earning her Ph.D. with Mosher in 1959, Lois J. Durham was hired by Stanford in a permanent position as an NMR spectroscopist in 1961 (36). Mosher recognized Durham as a coauthor on numerous publications and in the official history of the department (37):

Although she is not a member of the faculty, Lois Durham merits recognition as the longtime manager of the Nuclear Magnetic Resonance Laboratory. After receiving her Ph.D. in organic chemistry and spending a few years at SRI International, she accepted the position of managing the NMR lab. For 39 years she has trained undergraduate and graduate students in the operation of the instruments, which now number five. She is an invaluable member of the Chemistry Department.

Mosher's postdoctoral students were a very international group. Lotte Fikentscher was a researcher at the Max Plank Institute for Medical Research. Janet Samartino Plummer worked first for Parke-Davis and then Pfizer. Theresa M. Williams earned a position at Merck. Robyn L. Crumbie is a senior lecturer at the University of Western Australia.

The female Ph.D. students from the Mosher laboratory also continued work in chemistry. Elizabeth Parker Burrows also worked with Cope, and she is the one woman whose training was shared by the two men. Dorothy M. Feigl performed postdoctoral research at North Carolina State University and subsequently took a position at St. Mary's College (Notre Dame). Feigl has moved into administration at St. Mary's, serving as Vice President and Dean of the Faculty for fourteen years, before recently returning to chemistry (38). Betty McFarland stayed on at Stanford and work with Harden M. McConnell after her graduate work (39). Joel Schmiegel taught for a while at Marian College in Indianapolis, IN prior to the birth of her second child (40). Betty Ann Winter Stephenson worked in industry and taught at the University of Santa Clara and at Case Western Reserve University (41). Carolyn Lucille Heutter Fisher took a position at McCormick and has published extensively in the area of flavor chemistry (42). Natalie Lewis McClure took a postdoctoral position with Syntex, who then hired her into a permanent position. Alexandra Baran Shortt took a position with Stauffer Chemical Co. and later moved on to Pennzoil Products Co.

Women who took a masters degree from Mosher's group also went on to productive careers in the field. Joan Reinhart worked at the U. S. Naval Test Station in China Lake, CA. Anne Llyod Rieger went on to earn her Ph.D. at Columbia University and then obtain a research position at Brown University (43). Dolores Carlotta Miller found work with IBM. Jane Marie Marshburn took a position at Syntex, then with Gilead Sciences, Inc.

Cope and Mosher's Legacies; Awards in Their Names

In his lifetime Cope amassed a considerable estate from his work with pharmaceutical companies (18). Upon his death, he bequeathed half of this estate to the American Chemical Society to establish an award for outstanding achievement in organic chemistry. Recipients of the Arthur C. Cope Award (21a) have been named since 1973. Awardees are given \$25,000, a medallion, and a \$150,000 research grant. The awardees represent a veritable who's who of organic chemists. Ironically, none of these recipients is female. This is not surprising for the field, but extraordinary considering Cope's impact on the professional training of female scientists.

In 1984 the Arthur C. Cope Scholar Award was established as a consequence of astute investing and subsequent unexpected growth of the Cope Fund (21b). Recipients of this award are given \$5,000 and a \$40,000 research grant. Ten Arthur C. Cope Scholars are named annually; four between the ages of 36 and 49, four age 50 or older, and two 35 and younger. Of the 230 recipients of this award since 1985 (21b), only 14, or 6%, of the awardees are women. By comparison, the National Academy of Sciences chemistry division elected its first woman in 1978 and now lists eight women out of 201 current members (4%) (44). Markedly, three of the 14 female recipients received the award in 2008. While this one-year increase is notable, 11 of the 14 female awardees have received the award in the past 10 years, which is still only 11% of the Cope Scholar Awards given for that time period.

The Harry and Carol Mosher Award was established in 1980 by the Santa Clara Valley Section of the American Chemical Society (23). The award recognizes outstanding work in any subdiscipline of chemistry. Past recipients have included five women (18% of awardees). Although the representation of women for the Harry and Carol Mosher award is greater than that of the Cope Awards, neither award honors the true legacy of either man for mentoring all chemists, regardless of gender.

Table 1: Women At Bryn Mawr College who worked with Cope*

| Undergraduates | Ph.D. Students | Research Assistant |
|-----------------------|-----------------------------------|---------------------------|
| Ruth Rogan | Corris Mabelle Hofmann (1941) | Evelyn Margaret Hancock |
| Norma Finkelstein | Elizabeth Mary Osman (1942) | |
| Dorothea Peck | Elizabeth MacGregor Hardy (1942) | |
| Catherine Eide | Dorothea R. (Heyl) Hoffman (1942) | |
| Arsenia Arroyo | Mary Elizabeth Wright (1943) | |
| Kathryn Hoyle | | |
| Cornelia Wyckoff | | |
| Esther Hardenbergh | | |

*Women who were included as coauthors on papers or patents or women for whom a master's or doctoral thesis is found in the appropriate school library catalog are listed. It is possible that female undergraduates who worked with Cope or Mosher are not listed as Bryn Mawr, MIT, and Stanford do not catalog undergraduate theses.

Table 2: Women at MIT who worked with Cope

| Undergraduates | Masters Students | Ph.D. Students | Post-doctoral Fellows |
|-----------------------|------------------------------------|------------------------------|------------------------------|
| Aubrey Knowles | Anne Ames Gillis (1951) | Phyllis Louise Magat (1947) | Marion Burg |
| Hannelore Keller | Patricia A. Starke (1954) | Emily Lippincott Wick (1951) | Patricia A. Trumbull |
| | Phylis Tocco Moore (1959) | | Ruta K. Bly |
| | Mary J. (Hazard) Youngquist (1961) | | Elizabeth Parker Burrows |
| | Beverly Ann Pawson (1966) | | |

Table 3: Women from Stanford who worked with Mosher**

| Undergraduates | Masters Students | Ph.D. Students | Post-doctoral Fellows |
|-----------------------|---------------------------|---------------------------------------|------------------------------|
| Leslie Dean Turner | Mary Holbrook (1947) | Nydia B. Goetz-Luthy (1948) | Paula Kaufmann Loeffler |
| | Joan Reinhart (1950) | Elizabeth Parker Burrows (1956) | Erna Kaufmann |
| | Marilyn S. Gregory (1951) | Lois Jean Durham (1959) | Lotte Fikentscher |
| | Martha Helen Fronk (1957) | Dorothy Feigl (1965) | Janet Samartino Plummer |
| | Anne Lloyd Rieger (1959) | Betty Jean Gaffney McFarland (1965) | Robyn L. Crumbie |
| | Maravene Edelstein (1963) | Joel Marie Larkin Schmiegel (1967) | Theresa M. Williams |
| | Beverly Ann Braman (1967) | Betty Ann Winter Stephenson (1971) | |
| | Delores C. Miller (1975) | Carolyn Lucille Heutter Fisher (1978) | |
| | Jane M. Marshburn (1977) | Natalie Lewis McClure (1979) | |
| | | Alexandra Baran Shortt (1982) | |

**In the cases where an M.S. and Ph.D. were earned by the woman at Stanford, the final degree is indicated.

Conclusions

Women who worked with Cope and Mosher have gone on to become scientists of considerable talent. They have become noteworthy industrial scientists (Merck, American Cyanamid, Hoffman LaRoche, Kodak, Dupont, Syntex, IBM, Pfizer), leaders in the academic world (University of Iowa, MIT, Case Western, St. Mary's of Notre Dame, Brown University), government researchers (U. S. Naval Test Station, U. S. Army Biomedical Research & Development Laboratory) and respected by their professional peers (American Chemical Society). It would seem that Cope's most recognizable legacy—his fortune, in the forms of the Arthur C. Cope Award and Arthur C. Cope Scholar Award—is not reflective of his personal legacy of gender diversity in his research group. The recipients of the Carol and Harry Mosher Award come closer to representing the diversity of chemists mentored by Mosher.

As individuals, Cope and Mosher supported women scientists when many of their peers did not. Their motivation for mentoring, supporting, and collaborating with female chemists may never be fully appreciated. It is not clear why the subdiscipline has not recovered from its slow start with regard to women. Cope and Mosher demonstrated that women were able to perform top-notch science. Clearly, the women who were mentored by these two men have gone on to be successful scientists. These women became many of the first women to travel down their career paths, paths that were traveled as early as the 1940s. The continued relative shortfall of female Ph.D.s in organic chemistry could be improved by studying the examples of Cope and Mosher and learning from their leadership.

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FUTURE ACS MEETINGS

March 22-26, **2009**—Salt Lake City, UT
August 16-20, **2009**—Washington, DC
March 21-25, **2010**—San Francisco, CA
August 22-26, **2010**—Boston, MA
March 27-31, **2011**—Anaheim, CA
August 28-September 1, **2011**—Chicago, IL
March 25-29, **2012**—San Diego, CA
August 19-23, **2012**—New York, NY
April 7-11, **2013**—New Orleans, LA
September 8-12, **2013**—Indianapolis, IN
March 16-20, **2014**—Washington, DC
September 7-11, **2014**—San Francisco, CA
March 22-26, **2015**—Denver, CO
August 16-10, **2015**—Boston, MA
March 13-17, **2016**—San Diego, CA
August 21-25, **2016**—Philadelphia, PA
April 2-6, **2017**, San Francisco
September 10-14, **2017**, St. Louis