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Women in Chemistry: Exploring Their Contributions to the Development of Chemical Science

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Abstract: The role of women in chemistry has undergone significant changes throughout history despite facing various social and cultural challenges. In the past, men dominated chemistry, and female scientists' contributions were often overlooked or minimized. However, over time, women have increasingly demonstrated their outstanding contributions to the development of chemistry. Names like Marie Curie, who won two Nobels in physics and chemistry, and Rosalind Franklin, who was instrumental in the discovery of the structure of DNA, are undeniable proof that women have a crucial role to play in the advancement of chemistry. However, gender stereotypes and social norms often limit women's career options in science, and the influence of an academic environment that does not always support gender equality hinders their potential to develop fully. In addition, women are often faced with dual challenges, such as the double burden of managing a scientific career and family responsibilities. Based on these challenges, developing more inclusive and supportive policies and strategies is imperative to enable more women to engage in chemistry. In addition, creating a flexible work environment that prioritizes work-life balance will help reduce barriers for women in developing a career in chemistry. This research aims to trace the long journey of women in chemistry, identify the obstacles they face, and explore solutions and steps that can be taken to realize gender equality in this field. With these steps, it can be ensured that the full potential of women in chemistry can be realized so that they can contribute to advancing global science and technology more broadly.

Keywords: Chemistry, Contribution, Women

INTRODUCTION

Chemistry is one of the branches of natural science that has played a vital role in understanding natural phenomena and creating solutions to various global challenges. Over time, chemistry developments have broadened our horizons about matter and its reactions and provided the basis for innovations in areas such as health, energy, the environment, and materials technology. However, suppose you trace the history of the development of this science. In that case, the narrative of women's contributions is often on the periphery or even neglected, even though they have made no less essential contributions than their male counterparts (Rossiter, 1993).

One example of a monumental contribution comes from Marie Curie, the first woman to receive the Nobel Prize and the only one to win the Nobel Prize in two different fields, physics and chemistry. Her work on radioactivity paved the way for research in the nuclear and medical fields (Curie, 1904). On the other hand, Rosalind Franklin became a key figure in unraveling the structure of DNA, although recognition of her contribution only came years after her death (Mielczarek, 2006). Not only them, but many other female chemists, such as Dorothy Hodgkin's contributions to protein crystallography have also changed how we understand molecular processes (Hodgkin, 1965).

Unfortunately, women's contributions to chemistry often face various structural and cultural barriers. Gender discrimination, limited access to education, and minimal recognition of their work are challenges faced throughout history (Rossiter, 1993). Even in the modern era, despite increasing awareness of the importance of diversity and inclusiveness, women still face challenges in obtaining equal representation in the fields of science, technology, engineering, and mathematics (STEM).

This article aims to explore the contributions of female chemists to the development of chemistry, focusing on their achievements, scientific impact, and challenges. In addition, this research will also explore how their roles can inspire the younger generation, especially women, to engage in science. By highlighting their contributions and struggles, this article not only appreciates the role of women in the history of chemistry but also encourages society to continue to support diversity and gender equality in the world of science.

METHOD

This research uses a *literature* study method (*Library Research*) with the SALSA procedure (*Search, Appraisal, Synthesis, and Analysis*). This method was chosen because it allows researchers to collect and review relevant information from various previously published sources to provide a comprehensive overview of the topic under study. The first stage in this procedure, namely *Search*, was to search for related articles using keywords such as "Women in Chemistry" and "Contributions of Women to Chemistry" through academic databases such as Google Scholar, Scopus, etc. After the literature data is collected, the next step is carried out, namely *Appraisal*. At this stage, the journal's reputation, validity, and relevance of the articles obtained were assessed. This assessment aims to ensure that the literature used in the research is of good quality and has strong relevance to the topic discussed. The next stage is *Synthesis*. This stage is done by organizing the information that has been found into a more structured form so that it can be identified from the reputation of the journal obtained

to some crucial things in the article such as the name of the person discussed, his contribution, significance, to the conclusion of the article. The last stage is *analysis*. This stage is done by identifying the content of the information that has been compiled previously. This stage functions in making firm conclusions, providing new views, and supporting the main arguments in the article to be made. This identification aims to make the article capable of providing a clear and complete understanding of the topic being discussed.

RESULTS AND DISCUSSION

The first woman elected a Fellow of the Royal Society provides a comprehensive overview of the life and scientific achievements of Dame Kathleen Lonsdale FRS (1903-1971), a leading crystallographer. Lonsdale made significant contributions to the analysis of crystal structures, mainly using X-ray crystallography. She was instrumental in confirming the planar structure of benzene, which had a broad impact on organic chemistry. He discussed his advances in crystallography, especially methods of analyzing organic compounds and molecular structures in depth. In addition to her scientific contributions, Lonsdale was a leading figure in promoting women in science and as a peace activist, serving as a role model for the next generation of female scientists. Her work was honored with numerous awards and recognitions, including being named *Dame Commander of the British Empire* and a rare hexagonal diamond named Lonsdaleite named after her. Kathleen Lonsdale demonstrates her scientific brilliance and her dedication to social issues. It is an essential resource for understanding the historical development of crystallography and the role of women in science in the early 20th century (Wilson, 2021).

Her contribution to radiology and the development of radiotherapy, especially in applying radiation for cancer treatment, made Marie Curie famous in this field. In addition, Marie Curie is also renowned in the field of chemistry, especially for her discovery of radioactive elements such as radium and polonium, as well as her intensive research into the chemical properties of radiation. She even received the Nobel Prize in Chemistry in 1911 for contributing to the isolation of pure radium, cementing her position as a pioneer in radioactive chemistry. In addition to receiving two Nobel Prizes in Physics and Chemistry, Curie became essential in opening up opportunities for women in previously male-dominated fields of science. Marie Curie also contributed to the establishment of Radium in Paris, which later became the center of radiation research and treatment of cancer. In addition, her efforts in World War I introduced a mobile radiography unit to help treat wounded soldiers, eventually training more than 150 radiologists. Her achievements have made her a role model for future female scientists, particularly in radiobiology and radiotherapy (Gasinska, 2016).

In addition, one of the female luminaries in the field of chemistry is Professor Malika Jeffries-EL, a chemist and professor at Boston University known for her innovative research in developing organic semiconductors. With more than 50 peer-reviewed publications and over 200 conference presentations, Jeffries-EL not only contributes to scientific advancement but also plays an active role in promoting diversity in science. Professor Malika Jeffries-EL is a *Fellow of the American Chemical Society* and *the Royal Society of Chemistry and* the recipient of numerous awards recognizing her efforts in increasing the participation of women scientists and marginalized groups in the chemical sciences. The role of women in chemical science is not only limited to research but also includes teaching and advocacy. Professor Jeffries-EL, for example, is

committed to encouraging students from underrepresented groups to pursue STEM degrees. She is active in various professional organizations and has significantly supported women in science through mentoring and advocacy (Jeffries-el, 2024).

In the interview, Jeffries-EL emphasized the importance of creating support networks for women starting their careers in chemical research, including finding mentors and sponsors who can help them develop professionally. In addition, the challenges women face in this field are often related to the *systematic* bias that still exists in the scientific community. Jeffries-EL underscores the need for awareness of this bias and encourages institutions to provide bias training to reviewers and conference organizers. With these actions, it is hoped that a more inclusive environment will be created for women scientists to shine and contribute to their full potential. Overall, the contribution of women in chemistry is significant and growing. With figures like Professor Malika Jeffries-EL leading the way, the future of the field promises more innovation and diversity. Women serve as researchers, educators, mentors, and advocates, shaping the next generation of scientists and ensuring that their voices are heard in every aspect of chemistry research (Jeffries-el, 2024).

Rosalind Franklin made an essential contribution to understanding the structure of DNA through her meticulous X-ray fractionation technique. Through careful experimentation, Franklin managed to photograph DNA in two forms, namely form A (drier) and form B (wetter). Her diffraction photography, especially Photo 51, became the key for James Watson and Francis Crick to determine the double helix structure of DNA. Her findings cleared up the confusion in previous X-ray diffraction observations that showed a mixture of A and B forms of DNA. In addition, Franklin was the first scientist to provide accurate measurements for the diameter of the helix, the number of bases per turn of the helix, and the antiparallel orientation of the DNA strand, which was the foundation of Watson and Crick's DNA model. He conducted an in-depth analysis of the structure of DNA, discovering that DNA has a double helix shape with a backbone consisting of sugars and phosphates that protect the nitrogenous base pairs on the inside. Unfortunately, despite the importance of her data, Franklin did not receive the recognition she deserved during her lifetime, as she died several years before Watson, Crick, and Wilkins received the Nobel Prize in 1962 (Elkin, 2003).

Dorothy Mary Hodgkin is a British female chemist who contributed greatly to the field of science, especially in biochemistry and medicine. Dorothy Hodgkin is known as a scientist who succeeded in developing protein crystallography. Some of her influential discoveries in the field of science were the determination of the structure of penicillin that Ernst Boris Chain and Edward Abraham had previously researched and then the determination of the structure of vitamin B12, which earned her the Nobel Prize in Chemistry in 1964. In 1969, after 35 years of research and five years after receiving the Nobel Prize, Hodgkin could decipher the structure of insulin. He could interpret the structure of vitamin B12 and other complex molecules using X-rays, including penicillin and insulin. The structure of penicillin, for example, allows scientists to understand how antibiotics work to design new antibiotics that are more effective against bacterial infections. The same goes for insulin; understanding its structure allows further research into diabetes therapy, which is now an essential treatment for millions of people with diabetes (Butler, 2023).

Hodgkin was one of the pioneers in the field of modern structural biochemistry. Hodgkin studied the technique of X-ray crystallography, a method used to determine the three-dimensional structure of biomolecules. Hodgkin is one of the pioneers in the

field of modern structural biochemistry. The X-ray crystallography technique he developed and perfected became the primary method for determining the structure of biological molecules. Today, this method is used to understand many essential molecules, including proteins and enzymes, which form the basis of a wide range of research in pharmaceuticals, medicine, and biotechnology. The X-ray crystallography method developed by Hodgkin is an advanced technology for analyzing complex molecules. This method is the basis for many modern research instruments, including drug and vaccine research. This technology has even been further developed with methods such as cryo-electron microscopy (Butler, 2023).

The next female chemist was Carolyn Bertozzi, a chemist who contributed to the creation and development of bioorthogonal chemistry and its application to understanding the role of carbohydrates in biology. Carolyn created the Staudinger ligation and the concept of azide as a strong functional group for bioorthogonal chemistry. Carolyn's development of bioorthogonal chemistry can overcome the significant challenge of applying chemical reactions in biological environments, which is generally difficult due to various reactive groups in cells. In the study of glycans, this innovation enables direct detection and manipulation of glycans in living cells, which was previously difficult. In addition, Carolyn's technique also opens up opportunities for new glycan-based therapies, especially in the treatment of intractable cancers. The technology also enables molecular labeling with high specificity, potentially improving therapeutic efficacy. In addition, Carolyn and her trainees have applied this technique to glycoscience to identify and visualize glycans on living cells and support the development of chemical synthesis methods for glycoproteins and other related molecules (Kramer et al., 2023).

Asima Chatterjee, an Indian organic chemist, is recognized for her contributions to organic compounds and medicinal plant chemistry research, especially in alkaloids and plant-derived bioactive compounds. Chatterjee conducted in-depth research on alkaloids, which are organic nitrogen compounds found in many plants and have many medical benefits. He successfully isolated and understood the chemical structures of alkaloids from several medicinal plants common in India. His research laid the foundation for developing new medicines derived from natural materials. One of his most remarkable contributions was his research on developing anti-malarial compounds. Chatterjee researched plants native to India to find compounds effective against malaria, a widespread tropical disease. This discovery was crucial as it helped develop safer and more effective anti-malarial drugs. Her research also laid the foundation for further exploration of the potential of plants in medicine and provided great inspiration for women scientists. In addition to her scientific contributions, Chatterjee was a professor and mentor to many students, especially in India. Chatterjee became a pioneer in natural product chemistry in India. Her research encouraged the continued study of chemical compounds from traditional Indian plants, which later became the foundation for much research in pharmacology and medicinal chemistry in India and the world (De, 2015).

Professor Tricia Breen Carmichael is an influential female scientist in nanotechnology and modern electronic materials. With a Doctor of Philosophy (Ph.D.) from the University of Windsor in 1996, she continued her academic career through post-doctoral research at MIT and Harvard University, two of the world's leading institutions. Professor Carmichael's career took off when he joined the IBM TJ Watson Research Center, where he focused on developing organic electronics, a rapidly emerging field.

His research has led to significant innovations such as novel electronic textiles, wearable electroluminescent fabrics, and soft, stretchable light-emitting devices. One of his most outstanding achievements was the development of the first transparent butyl rubber for next-generation devices (Carmichael, 1996).

Currently, Professor Carmichael leads an interdisciplinary research program on stretchable and wearable electronic devices. He is also actively promoting equality, diversity, and inclusion in academia as editor-in-chief of the Flexible and Printed Electronics journal and director of equality, diversity, and inclusion for the Canadian Chemical Society. Her dedication to EDI (Equality, Diversity, and Inclusion) has been recognized through numerous awards, including the Mary Lou Dietz Equity Leadership Award. Despite facing challenges as a woman in a male-dominated field of science, Professor Carmichael remains optimistic and hopes to create a more inclusive academic environment where the term "women in chemistry" is no longer relevant. Through her dedication to research that is relevant to the needs of society and her fight for gender equality in the world of science, she has become an inspirational figure to many. Therefore, Professor Tricia Breen Carmichael is a successful scientist and an ideal example of a leader committed to creating positive change in the global scientific community (Carmichael, 1996).

Dr. Ritika Gautam-Singh is a prominent chemical scientist in biological inorganic chemistry. She is an Assistant Professor at the Indian Institute of Technology (IIT) in Kanpur, India, where she leads research on metal-based drug development for medical therapy, synthetic immunotherapy, and diagnostics. His primary focus is on utilizing metal-ligand interactions to create molecules that can disrupt metal homeostasis in cells, which has great potential in addressing various diseases, including cancer, neurodegenerative disorders, microbial infections, and metabolic and autoimmune syndromes. His research combines coordination chemistry, proteomics, and metabolomics to create highly specific and compelling therapeutics (Kanpur, 2024).

Dr. Ritika did her undergraduate studies at Banaras Hindu University and IIT Delhi and continued her doctoral studies at the University of Arizona, USA. She was also a research fellow at The Scripps Research Institute California before returning to India in 2019 to form her research group. Her dedication is recognized globally, with awards such as Royal Society of Chemistry Emerging Investigator and American Chemical Society Rising Star in 2023. She was appointed Associate of the Indian Academy of Sciences in 2024. As one of the inspiring female figures in chemistry, Dr. Ritika drives scientific innovation and showcases women's vital role in advancing science globally (Kanpur, 2024).

The following female chemists are Helma Wennemers, Christina Moberg, and Luisa De Cola. They discuss the contribution of women in chemistry and portray the current state of gender equality in science, especially in STEM (Science, Technology, Engineering, and Mathematics). Although the contribution of women in chemistry is increasing, data shows that they are still underrepresented. Data from UNESCO shows that only 28% of researchers worldwide are women, with disparities across countries. Countries such as Germany and France have a relatively low number of female researchers compared to Eastern European countries such as Lithuania and Latvia, which have gender equality in research. In addition, there is a decline in the number of women in research careers. This phenomenon is called the '*leaky pipeline*' where women leave science careers after higher education, often due to a lack of career flexibility, particularly for those with family responsibilities (D'Andola, 2016).

In this regard, social media and support communities play an important role in helping women in science to share experiences and discuss gender issues despite the risk of attacks from "trolls" or gender-based harassment. Barriers that limit women to high-level careers in research should be removed to maximize potential for innovation and creativity. To increase the representation of women in science, efforts can be made, such as training and mentoring programs, supporting policies for researchers with families, and countering the gender bias within academia. Organizations such as the Athena SWAN Charter and the Daphne Jackson Trust are examples of initiatives supporting women in research (D'Andola, 2016).

CONCLUSIONS

Women have made significant contributions to the field of chemistry despite the social and cultural challenges they have faced. Figures such as Marie Curie, Rosalind Franklin, and other female scientists have played an essential role in the advancement of chemistry. Despite progress, there are still gender stereotypes and structural barriers that limit women's participation. Therefore, there is a need for more inclusive policies and supportive work environments to encourage more women to engage in science, and there is an importance of support and policies to increase women's representation in STEM fields.

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