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IT IS TIME TO PAY TRIBUTE TO WOMEN IN SCIENCE: THE WOMEN WHO WON THE NOBEL PRIZES IN CHEMISTRY AND PHYSIOLOGY OR MEDICINE

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We are all giants, raised by pygmies,
who have learned to walk with
a perpetual mental crouch
R.A. Wilson

In the 21st century, it is time to recognize the essential role of women in science. The study carried out by women-scientists makes it possible to combine brightness of mind, deep knowledge with humaneness and wisdom. Their approaches to the problems and the ways to solve them are largely determined by their maps of meaning and existential experience that can enrich and expand the scientific field and, as a result, can offer unexpected but most effective ways to solve the problem. However, women face obstacles in advancing their careers in science, and the situation is even more discouraging when it comes to winning science awards, the most prestigious of which is the Nobel Prize. Between 1901 and 2023, the Nobel Prizes were awarded 621 times to 965 individuals and 27 organizations, but only 64 of them were women-scientists. While we recognize and praise all women – Nobel laureates, this paper pays special attention to women who have received Nobel Prizes in Chemistry and Physiology or Medicine and briefly outlines their scientific achievements. A more detailed description of their life and scientific journey will be provided in subsequent articles.

K e y w o r d s: women-scientists, women – Nobel Prize winners, the Nobel Prize, the Nobel Prize in Chemistry, the Nobel Prize in Physiology or Medicine.

Dedicated to each and every woman in science

February 11 is the International Day of Women and Girls in Science that aims to promote full and equal access to science and participation in science for woman and girls around the globe. This day was implemented by UNESCO and UN-Women in collaboration with civil society partners and institutions in 2015 [1]. The promotion of gender equality in the field of science and innovation is a part of the struggle for gender equality, which is one of the priorities of the contemporary world. Its awareness and removal of the “barriers” that impede the development of equal relationship between men and women meet the goals of a humanistic society.

The continuous struggle for gender equality has led to certain changes in public consciousness, but no country, as well as no field of activity has

yet achieved equality between women and men [2]. Civil liberties, sustainable development, peaceful future will remain abstract concepts unless they can be supported by women's chances to realize their potential, their own life projects [3]. The International Day of Women and Girls in Science serves as a reminder of the role of women and girls in scientific research, acknowledges their valuable contribution to science and society, and encourages the next generations of women to pursue careers in science [4].

However today, women and girls are still excluded from participating fully in science and innovations: women constitute a minority in the research world. If women are on a par with men at the bachelor's and master's levels (53%), at the PhD level they slip beneath parity to 43%. The share of women in research constitutes 28% only. Still now, women have less access to research funding and obtaining patents than men; they are less represented in prestigious universities, among senior faculty, as peer reviewers, on editorial boards and research councils; their research is less published in high-impact scientific journals [5]. "A combination of factors reduces the proportion of women at each stage of a scientific career: the graduate-level environment; the maternal wall/glass ceiling; performance evaluation criteria; the lack of recognition; lack of support for leadership bids; and unconscious gender bias" [5, p. 98].

Unfortunately, women do not have the same opportunities as men, cannot benefit from the results of research, or freely choose the profession to which they are drawn. Unequal treatment of individuals based on gender discrimination/gender stereotypes has led to negative consequences in various areas of society including science. The attrition of talented women from the science system is a serious loss in investment [5]. This is a wake-up call that indicates a huge loss of human potential for both women and men. Equal rights and opportunities for men and women are fair and just not only in terms of the moral point of view, but also in terms of the development of a global society [6].

If women face obstacles in advancing their careers in science, the situation is even more discouraging when it comes to winning science awards, the most prestigious of which is the Nobel Prize that is awarded to "those who, during the preceding year, shall have conferred the greatest benefit on mankind" [7]. The Nobel Prizes in Physics, Chemistry, Physiology or Medicine, Literature and Nobel Peace Prize have been awarded since 1901 and the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel – since 1968. Between 1901 and 2023, the Nobel Prizes were awarded 621 times to 965 individuals and 27 organizations [8]. Only 64 of them were women-scientists: among them 5 women received the Nobel Prize in Physics, 8 – in Chemistry, 13 – in Physiology or Medicine, 17 – in Literature, 19 were awarded the Peace Prize, and 3 – the Prize in Economic Sciences [9]. Marie Curie received the Nobel Prize twice: the Nobel Prize in Physics 1903 and the Nobel Prize in Chemistry 1911. Thus, today only 6.6% of Nobel laureates are women. When it comes to hard sciences, this figure has dropped by 2.7%. Although the situation has been slowly improving, this disproportion is glaring given the number of women in science. To tackle this bias, deep changes need to be made. G.K. Hansson, the Secretary General of the Royal Academy of Sciences and Vice Chairman of the Board of Directors of the Nobel Foundation, turned to scientists asking them to consider gender and geography in their nominations and also drew attention to the need to increase the number of women in the prize-giving bodies: "We don't work in a vacuum. We need the scientific community to see the women scientists, and to nominate those who have made outstanding contributions" [10]. He emphasizes that the Academy will continue to instruct scholars "to make an extra effort to identify women scientists who they think should be considered for the Prize" [11].

However, the efforts to diversify Nobel Prize winners is a slow-going process. As G.K. Hansen noted, despite the clear gender imbalance among Nobel laureates, the issue of gender quotas had been dismissed: "We have decided we will not have quotas for gender or ethnicity. We want every laureate [to] be accepted ... because they made the most important discovery, and not because of gender or ethnicity. And that is in line with the spirit of Alfred Nobel's last will" [12].

In addition to the socially ingrained idea that science is a "men's business", common belief that women are less competent in science, everyday discrimination such as underpayment, lack of scientific recognition and promotion primarily at high levels, critics note that the Nobel selection process itself is too narrow. Nobel Prizes are mainly awarded to those discoveries that are significant on a global level. However, our big world consists of many communities, cultures, countries. Although the world is one, it is not homogeneous. And discoveries on a lo-

cal level, which do not receive worldwide resonance, can ultimately affect the transformation of the entire world community. An associate professor at the University of Maryland K. Griffin rightly pointed out that it is time to think broadly about what it means to have a significant scholarly impact, "women and people of color often conduct research projects that directly relate to a specific community, and that that work can be more transformative than some of the scientific advances that generate international recognition" [11].

It is clear that there is still a long road ahead. Not only the Nobel Committee, the scientific community, but also the global society need to take a different look at the role of women in science, overcome subconscious bias, and pay tribute to those who rightfully deserve the highest recognition. Otherwise, as a New Zealand physicist L. Winkless emphasized, "if the committee had had their way, Marie Curie would not have received the 1903 physics prize" [12].

While we recognize and praise all women – Nobel laureates, allow us to pay special attention to women who have received Nobel Prizes in Chemistry and Physiology or Medicine.

Marie Curie

(The Nobel Prize in Physics 1903;
The Nobel Prize in Chemistry 1911)

Marie Curie [13]

The first woman to receive the Nobel Prize was a Polish-French physicist and chemist **Marie Skłodowska-Curie**. She was also the only woman to receive two Nobel Prizes. Marie Curie discovered new elements and named them polonium and radium. She also coined the term "radioactive" to describe them. She was awarded the Nobel Prize in Physics 1903 along with Antoine Henri Becquerel and her husband Pierre Curie. This prize was divided, one half awarded to A.H. Becquerel "in recognition of the extraordinary services he has rendered by his discovery of the spontaneous radioactivity", the other – jointly to Pierre and Marie Curie "in recognition of the extraordinary services they have rendered by their joint researchers on the radiation phenomena discovered by Professor Henri Becquerel" [14]. And if evil tongues could say that Marie Curie owed her first prize to her husband, then the second prize she received refuted not only this statement, but the very concept of the incompetence of women in science.

In 1911, Marie Curie won the Nobel Prize in Chemistry "in recognition of her services to the advancement of chemistry by the discovery of the elements radium and polonium, by the isolation of radium and the study of the nature and compounds of this remarkable element" [15].

As Marie Curie put it, "I am among those who think that science has great beauty. A scientist in his laboratory is not only a technician, he is also a child placed before natural phenomenon, which impress him like a fairy tale" [16].

Irène Joliot-Curie

(The Nobel Prize in Chemistry 1935)

Irène Joliot-Curie [17]

French chemist, physicist and politician **Irène Joliot-Curie** was the elder daughter of Pierre and Marie Skłodowska-Curie and the wife of Frederic Joliot-Curie, with whom she collaborated on natural and artificial radioactivity, transmutation of elements, and nuclear physics [18]. Their discovery paved the way to medical advances, especially in the fight against cancer [17]. In 1935, the couple shared the Nobel Prize in Chemistry "in recognition of their synthesis of new radioactive elements"

[19]. This made Frederic and Irène Joliot-Curie the second ever-married couple to win the Nobel Prize (after her parents) [20].

Gerty Cori

(The Nobel Prize in Physiology or Medicine 1947)

Gerty Cori [21]

Gerty Theresa Cori was an Austrian-American biochemist. Together with her husband Carl Ferdinand Cori, she was engaged in the research of carbohydrate metabolism. They discovered glucose-1-phospate, a derivative of glucose, the form in which glucose is stored in muscles. They also identified phosphorylase, the enzyme that breaks down glycogen in the Cori ester [22]. Their work on carbohydrate metabolism, which changed the understanding of diabetes, led to the Nobel Prize [23]. The Nobel Prize in Physiology or Medicine 1947 was divided. One half awarded to Carl and Gerty Cori "for their discovery of the course of the catalytic conversion of glycogen" and the other – to Bernardo Alberto Houssay "for his discovery of the part played by the hormone of the anterior pituitary lobe on the metabolism of sugar" [24]. In the radio series "This I Believe", Gerty Cori said, "The love for and dedication to one's work seem to me to be the basis for happiness" [25].

Dorothy Crowfoot Hodgkin

(The Nobel Prize in Chemistry 1964)

Dorothy Hodgkin [26]

A renowned British chemist **Dorothy Mary Crowfoot Hodgkin** was the third woman to win the Nobel Prize in Chemistry. According to Dorothy Hodgkin, she was captured for life by chemistry and by crystals [27]. This life-long passion had had the greatest impact on her life [28]. Among her most influential discoveries are the confirmation of the structure of penicillin, mapping the structure of vitamin B12. She also elucidated the structure of insulin. She advanced the technique of X-ray crystallography to determine the structure of biomolecules, which has become essential for structural biology [29]. In 1964, she won the Nobel Prize in Chemistry "for her determinations by X-ray techniques of the structures of important biochemical substances" [30]. At her memorial service, M. Perutz, her long-time collaborator, said, "She radiated love: for chemistry, her family, her friends, her students, her crystals and her college … Her love was combined with a brilliant mind and an iron will to succeed, regardless of her frail and later severely crippled body. There was magic about her person" [27].

Rosalyn Yalow

(The Nobel Prize in Physiology or Medicine 1977)

Rosalyn Yalow [31]

An American medical physicist **Rosalyn Yalow** became the second woman to win the Nobel Prize in the field of medicine for co-developing radioimmunoassay (RIA) – the technique that uses radioactive isotopes to quickly and precisely measure concentrations of hormones, vitamins, viruses, and many other substances [32]. The technique can be used to identify hormone-related health problems, to detect foreign substances in the blood, to measure the effectiveness of dose levels of drugs and antibiotics [33]. In 1977, the Nobel Prize in Physiology or Medicine was divided, one half jointly to Roger Guillemin and Andrew V. Schally "for their discoveries concerning the peptide hormone production of the brain" and the other half to Rosalyn Yalow "for the development of radioimmunoassays of peptide hormones" [34]. Although Yalow's research was conducted in conjunction with an American physician and scientist Solomon Aaron Berson, the latter died in 1972 and could not share their ultimate success, because the Nobel Prize cannot be awarded posthumously. Successfully balancing her scientific career with her family life, shunning feminist ideas, Rosalyn Yalow still advocated for including more women in science [35]. Discussing equality of opportunity, she said, "We cannot expect in the immediate future that all women who will seek it will achieve [it]. But if women are to start moving toward that goal, we must believe in ourselves or no one else will believe in us; we must match our aspirations with the competence, courage and determination to succeed, and we must feel a personal responsibility to ease the path for those who come after us. The world cannot afford the loss of the talents of half its people if we are to solve the many problems that beset us" [36].

Barbara McClintock

(The Nobel Prize in Physiology or Medicine 1983)

Barbara McClintock [37]

An American scientist and cytogeneticist **Barbara McClintock** was one of the greatest geneticists of the 20th century. She led the field in the study of chromosomes and how they affect the behavior of the cell [38]. Her studies of genetic mutation in maize pawed the way to her discovery of "mobile genetic elements", i.e., genes that move from one chromosome to another [39]. Her work on controlling elements and gene regulation was conceptually difficult and was not immediately accepted by her colleagues. It took many years for her discoveries to gain global recognition. In 1983, Barbara McClintock won the Nobel Prize in Physiology or Medicine "for her discovery of mobile genetic elements" [40]. Barbara McClintock was the first woman to receive an unshared Nobel Prize in that category. She described her life and scientific position as follows, "over the many years, I truly enjoyed not being required to defend my interpretations. I could just work with the greatest of pleasure. I never felt the need nor the desire to defend my views. If I turned out to be wrong, I just forgot that I ever held such a view. It didn't matter" [41].

Rita Levi-Montalcini

(The Nobel Prize in Physiology or Medicine 1986)

Rita Levi-Montalcini [42]

An Italian American neurobiologist **Rita Levi-Montalcini** made a huge contribution to the field of neurobiology, especially the area of neurogenesis. Collaborating with the zoologist Viktor Hamburger who was studying the growth of nerve tissue in chick embryos, they discovered that a variety of mouse tumor spurred nerve growth when implanted into chick embryos. The scientists traced the effect to the substance in the tumor which they named nerve-growth factor (NGF) [43]. Rita Levi-Montalcini showed that the tumor caused similar cell growth in a nerve-tissue culture kept alive in the laboratory. NGF represented a whole new type of control mechanism in cell differentiation. For years, Rita Levi-Montalcini worked with the American biochemist Stanley Cohen who isolated this factor and deduced its chemical structure [44]. Their joint efforts and services to science were appreciated and they won the Nobel Prize in Physiology or Medicine 1986 "for their discoveries of growth factor" [45]. Throughout her life, Rita Levi-Montalcini combined her scientific research with public activity. In 1999, she was appointed ambassador to the Food and Agriculture Organization of the United Nations and was engaged in public activity to combat hunger [46]. With her twin sister Paola, Rita Levi-Montalcini established the Rita Levi-Montalcini Onlus Foundation – a fellowship program for young female African scientists [42]. In 2001, the Italian senate appointed her a senator for life.

Gertrude Belle Elion

(The Nobel Prize in Physiology or Medicine 1988)

Gertrude Elion [47]

Gertrude Belle Elion was a distinguished American biochemist and pharmacologist who devoted her life to research to combat some of the world's most dangerous diseases. Together with George Hitchings, an American biochemist and pharmacologist, using a method known as "rational drug design", Gertrude Elion created a number of effective drugs to combat leukemia, herpes, gout, malaria, autoimmune disorders. They devised a system for designing drugs that led to the development of the AIDS drug AZT. Gertrude Elion pioneered the development of two drugs that interfered with the reproductive process of cancer cells to cause remissions in childhood leukemia. In some years, she created the first immuno-suppressive agent. Eventually, her work led to the development of the first drug used against viral herpes [48; 49]. Fruitful collaborative research of Gertrude Elion and George Hitchings paved the way to the Nobel Prize. The Nobel Prize in Physiology or Medicine 1988 was awarded jointly to Sir James W. Black, Gertrude B. Elion and George H. Hitchings "for their discoveries of important principles for drug treatment" [50]. Recalling her challenging path to science, Gertrude Elion noted, "Time passes rapidly when you are having fun. Have a goal that you really care about... Don't be afraid of hard work. Nothing worthwhile comes easily. Don't let others discourage you or tell you that you can't do it. In my day I was told women didn't go into chemistry. I saw no reason why we couldn't. It's true it took seven years of various jobs, including a

year in graduate school and two years of high school teaching before the shortage of men in civilian jobs gave me the opportunity to prove myself. But after that, I never looked back" [51].

Christiane Nüsslein-Volhard

(The Nobel Prize in Physiology or Medicine 1995)

Christiane Nüsslein-Volhard [52]

A prominent German developmental biologist and geneticist **Christiane Nüsslein-Volhard** is the only woman from Germany to have received the Nobel Prize in the sciences. Her research focuses on the genetic and molecular development analysis of animals, particularly the fly Drosophila melanogaster and the zebrafish Danio rerio. "I immediately loved working with flies. They fascinated me, and followed me around in my dreams", she said [53]. Together with Eric Wieschaus, an American evolutionary developmental biologist, Christiane Nüsslein-Volhard discovered about 120 genes in systematic studies at the EMBL in Heidelberg that have important functions in shaping the fly embryo, especially its division into segments. This discovery has contributed significantly to understanding general mechanisms of pattern formation during animal development. Many of the new genes also play important roles (in modified form) in vertebrate development and in carcinogenesis [54]. Christiane Nüsslein-Volhard has received numerous awards, and the Nobel Prize is one of them. The Nobel Prize in Physiology or Medicine 1995 was awarded jointly to Edward B. Lewis, Christiane Nüsslein-Volhard and Eric F. Wieschaus "for their discoveries concerning the genetic control of early embryonic development" [55]. Christiane Nüsslein-Volhard always sees beauty in her scientific work and in the world around her: "Initially, I was just struck by the beauty of the fish, like I had been by the segmentation pattern of flies: it's always nicer to work on something you find beautiful" [53].

Linda Brown Buck

(The Nobel Prize in Physiology or Medicine 2004)

Linda Buck [56]

Linda Brown Buck is an American biologist best known for her work on the olfactory system [57]. She explores the mechanisms underlying smell, taste, and pheromone sensing in mammals. In the olfactory system, hundreds of different odorant receptors are used in a combinatorial fashion to encode the identities of thousands of odorous chemicals. Her research has revealed how combinatorial codes are represented in the nose, olfactory bulb, and olfactory cortex to ultimately generate diverse odor perceptions [57]. Together with an American molecular biologist Richard Axel, they showed that each olfactory receptor neuron remarkably only expresses one kind of olfactory receptor protein, and that the input from all neurons expressing the same receptor is collected by a single dedicated glomerulus of the olfactory bulb [58]. In 2004, Linda Buck and Richard Axel became the recipients of the Nobel Prize in Physiology or Medicine "for their discoveries of odorant receptors and the organization of the olfactory system" [59]. The message from a woman to all women in science can be summed up in Buck's words, "As a woman in science, I sincerely hope that my receiving a Nobel Prize will send a message to young women everywhere that the doors are open to them and that they should follow their dreams" [60].

Françoise Barré-Sinoussi

(The Nobel Prize in Physiology or Medicine 2008)

Françoise Barré-Sinoussi [61]

Françoise Barré-Sinoussi is a French virologist and activist who, while working with Luc Montagnier at the Pasteur Institute, discovered human immunodeficiency virus (HIV) in 1983. Through dissection of an infected patient's lymph node, they determined that AIDS was caused by a retrovirus, which came to be known as HIV. This discovery led to blood tests to detect the infection and finally to the development of new diagnostic methods and antiviral drugs that began to keep AIDS patients alive [62, 63]. Françoise Barré-Sinoussi has been strongly implicated in promoting integration between research, training, and actions in resource limited countries, in particular through the Institut Pasteur International Network and the coordination of the ANRS research programs in Cambodia and Vietnam [64]. "Of course, I am an activist. So much work went into achieving a diagnostic tool and a treatment, and now we even have a tool for prevention. There has been enormous scientific progress – and yet people are still dying of AIDS. How can I accept this? I cannot. It's a matter of equality. Everybody has a right to live", Françoise Barré-Sinoussi said [65]. Barré-Sinoussi's in-depth research resulted in the awarding of the Nobel Prize. The Nobel Prize in Physiology or Medicine 2008 was divided, one half awarded to Harald zur Hausen "for his discovery of human papilloma viruses causing cervical cancer", the other half jointly to Françoise Barré-Sinoussi and Luc Montagnier "for their discovery of human immunodeficiency virus" [66].

Françoise Barré-Sinoussi's message to the world is: "Life is short. And life is the only thing that matters. I would tell others to be tolerant because it is important for peace. It's also important to fight against inequality. Science can achieve all the progress it wants, but if people don't accept or help each other, that progress will be very slow" [65].

Elizabeth Helen Blackburn and Carol Widney Greider

(The Nobel Prize in Physiology or Medicine 2009)

Carol W. Greider (left) and Elizabeth H. Blackburn [67]

In 2009, the Nobel Prize in Physiology or Medicine was awarded jointly to **Elizabeth H. Blackburn**, **Carol W. Greider** and Jack W. Szostak "for the discovery of how chromosomes are protected by telomeres and the enzyme telomerase" [68]. These scientists explained how the chromosomes that carry the genes are copied in their entirety during cell division and protected against breakdown. The answer to this question lies in the telomeres – the chromosomes' ends, and in telomerase – the enzyme that forms them. An Australian-born American molecular biologist and biochemist Elizabeth Blackburn and a Canadian American biologist Jack Szostak were the first to show that the unique DNA sequence contained in the telomeres serves to protect the chromosomes. An American molecular biologist Carol Greider together with Elizabeth Blackburn were then able to show how the telomeres could be extended by the enzyme telomerase [69]. The research on the effects of chromosomal protection from telomerase and the impact this has on cellular division has become a revolutionary catalyst in the field of molecular biology [70].

The link between telomere length and the cell health led Elizabeth Blackburn to ask broader questions about personal and public health. For example, in her interview she said that "exercise mitigates the effects of stress – and stress, we know, shortens tel-

omeres. In fact, early studies indicate that stress reduction techniques like meditation help people maintain the length of their telomeres. The studies are small, but they all point in the same direction" [71]. Although the lab scientist was very careful with her assertions, contemporary studies confirm her words [72-74].

Carol W. Greider, being concerned with, as she puts it, "under-representation of the 50% of the brain power of this world", encourages women who want to balance a family and a career they love to "find a way to do it. And there is not one way" [75].

Ada Yonath

(The Nobel Prize in Chemistry 2009)

Ada Yonath [76]

2009 was a very successful year for women-scientists. The Nobel Prize in Chemistry 2009 was awarded to **Ada Yonath**, an Israeli protein crystallographer, best known for her pioneering work on the structure of ribosomes. She is the first ever Israeli woman to receive this prestigious prize and the first woman from the Middle East to win the Nobel Prize in the sciences [77]. According to Ada Yonath, her success has been grounded in curiosity, dedication, and passion [78]. Ada Yonath pioneered the development of new approaches to the study of structural characteristics of complex molecules; determined the three-dimensional atomic arrangement of a large ribosomal subunit. Her research revealed the complex architecture of ribosomes, and she identified structures resembling tunnels, through which newly synthesized polypeptide chains were passed during protein synthesis [79]. She utilized new techniques, such as cryo-crystallography [80]. She also successfully determined the atomic structure of the small ribosomal subunit of Thermus thermophilus. Her later research was concerned with determining the atomic structures of antibiotics [79]. The Nobel Prize in Chemistry 2009 was awarded jointly to Venkatraman Ramakrishnan, Thomas A. Steitz and Ada E. Yonath "for studies of the structure and function of the ribosome" [81]. Ada Yonath compared her scientific journey "to climbing Mount Everest only to discover that a higher Everest stood in front of us" [82].

May-Britt Moser

(The Nobel Prize in Physiology or Medicine 2014)

May-Britt Moser [83]

May-Britt Moser is a Norwegian psychologist and neuroscientist known for her work on spatial orientation and spatial memory specifically and cognition more generally. Together with her husband, a Norwegian neuroscientist Edvard I. Moser, she made a huge contribution to the discovery of grid cells in the brain and the elucidation of their role in generating a system of mental coordinates by which animals are able to navigate their environment [84]: "the ability to figure out where we are and where we need to go is key to survival. Without it, we, like all animals, would be unable to find food or reproduce. Individuals – and, in fact, the entire species – would perish" [85]. This research enabled scientific community to gain new insights into cognitive processes and spatial deficits associated with Alzheimer disease, because brain areas relating to orientation are the first to be affected by it [86]. For her discoveries, May-Britt Moser became the co-recipient of the 2014 Nobel Prize in Physiology or Medicine which was divided: one half awarded to John O'Keefe, the other half jointly to May-Britt Moser and Edvard I. Moser "for their discoveries of cells that constitute a positioning system in the brain" [87]. May-Britt Moser states that she has never felt that her gender has been an impediment in her work: "I see that female re-

searchers in other countries have had a much tougher time than I have", "It's fantastic to live in a society where everyone is given an equal opportunity" [83].

Tu Youyou

(The Nobel Prize in Physiology or Medicine 2015)

Tu Youyou [88]

Tu Youyou is a Chinese pharmaceutical chemist and malariologist. Referred to as the "Three-Without Scientist", she discovered artemisinin and its derivatives, used to treat malaria without a doctoral degree, work or research experience abroad, or affiliations with national academies [89]. Her breakthrough in the twentieth-century tropical medicine saved millions of lives and represents one of the significant contributions of the ancient culture of China to global health [90]. Tu Youyou applied traditional Chinese medical knowledge to the modern drug discovery. During the Vietnam War, Tu Youyou was appointed to lead Project 523 aimed at discovering a treatment for malaria. Investigating ancient prescriptions and visiting practitioners of traditional Chinese medicine, Tu Youyou and her team screened over 2 000 traditional recipes and made 380 herbal extracts, which were tested on mice [91]. A key insight into an anti-malaria drug was provided by Ge Hong (III – IV century AD) – a philosopher, alchemist, Taoist practitioner, physician, and writer and his treatise "Zhou Hou Jiu Zu Fang" (A Handbook of Formulas for Emergencies) [92]. Like many Taoist masters, Ge Hong pursued the idea of creating a medicine that would turn people immortal. It's not for nothing that they say that Taoism is a "drug store". Ge Hong discovered numerous herbal remedies to treat diseases. Tu Youyou was inspired by what Ge Hong wrote and eventually extracted artemisinin from the sweet wormwood plant. Unlike other discoveries first made in a laboratory, Tu Youyou turned to the ancient traditional Chinese medicine and, wider, to the centuries-old authentic multifaceted Chinese wisdom [93]. She is convinced that "Chinese medicine will help us conquer life-threatening diseases worldwide, and that people across the globe will enjoy its benefits for health promotion" [94]. The Nobel Prize in Physiology or Medicine 2015 was divided, one half jointly to William C. Campbell and Satoshi Ōmura "for their discoveries concerning a novel therapy against infections caused by roundworm parasites" and the other half to Tu Youyou "for her discoveries concerning a novel therapy against Malaria" [95].

Frances Hamilton Arnold

(The Nobel Prize in Chemistry 2018)

Frances Arnold [96]

Frances Hamilton Arnold, an American chemical engineer, has followed her own path from the time she was a child. Her love for freedom and independence is reflected in her scientific work – she turned bioengineering upside down. Admiring "beauty and complexity of the biological world" [97], she "figured out how to let evolution be her partner in the lab" [98]. Frances Arnold altered the enzyme subtilisin E, so it would work in the solvent dimethylformamide instead of in the watery environment of a cell. Introducing many random mutations into the genetic code of bacteria that made subtilisin E, as well as her mutated enzymes into an environment that contained both dimethylformamide and casein, she selected the new enzyme that was best at breaking down casein in dimethylformamide and introduced random mutations into that enzyme. A

mutated subtilisin E was 256 times better at breaking down casein in dimethylformamide than the original. Frances Arnold and her lab extended the technique of directed enzyme evolution to change enzymes for reactions that no enzyme had catalyzed before. They also evolved enzymes to make substances with bonds that do not occur in biology, such as bonds between carbon and silicon, carbon and boron [99]. She had applied new techniques to solve important problems in biocatalysis: from pharmaceutical synthesis to biofuels to sensors and diagnostics [100]. This profound innovative work has been recognized by numerous awards, including the Nobel Prize. The Nobel Prize in Chemistry 2018 was divided, one half awarded to Frances H. Arnold "for the directed evolution of enzymes", the other half jointly to George P. Smith and Sir Gregory P. Winter "for the phage display of peptides and antibodies" [101]. Frances Arnold's life credo can be expressed in her words: "If you're going to change the world, you've got to be fearless" [98].

Emmanuelle Charpentier and Jennifer A. Doudna

(The Nobel Prize in Chemistry 2020)

Emmanuelle Charpentier (left) and Jennifer A. Doudna [102]

Two years later, the two women-scientists received the Nobel Prize in Chemistry again. This time a breakthrough in science was made by a French microbiologist, geneticist, and biochemist **Emmanuelle Charpentier** and an American biochemist **Jennifer A. Doudna**. Emmanuelle Charpentier has devoted herself to understanding the fundamental mechanisms of diseases, with a particular interest in infections caused by Gram-positive pathogenic bacteria such as Listeria, staphylococci and streptococci [103]. Jennifer Doudna investigated the control of genetic information by certain small RNAs and became interested in CRISPR, which is the part of the bacterial immune system. It originates with RNA sequences from invading viruses that become incorporated into bacterial genomes. The viral sequences reside as DNA in the spacers between short repeating blocks of bacterial DNA sequences. The next time the virus invades the bacterial cell, the spacer DNA is converted to RNA. The Cas9 enzyme and a second RNA molecule attach to the newly coded RNA, which then seeks out matching strands of viral DNA. When encountered, Cas9 cuts the viral DNA, preventing the virus's replication. Throughout their fruitful cooperation, Jennifer Doudna and Emmanuelle Charpentier found that the guide RNA sequence could be changed to direct Cas9 to a precise DNA sequence [104]. The researchers discovered the way to alter any organism's DNA – the genome-editing technique known as CRISPR-Cas9 [105]. Using CRISPR/Cas9 genetic scissors, researchers can change the DNA of living organisms with very high precision [106]. Their discovery immediately transformed the scientific landscape and created new opportunities for the treatment of diseases. It expands horizons in immunotherapy, gene- and cell therapy, biotechnology, agriculture. In 2020, Emmanuelle Charpentier and Jennifer A. Doudna won the Nobel Prize in Chemistry. It was awarded to them "for the development of a method for genome editing" [107]. Emmanuelle Charpentier and Jennifer A. Doudna are the first two women to share the Nobel Prize. Igniting the power of women, Emmanuelle Charpentier said, "I wish that this will provide a positive message specifically for young girls who would like to follow the path of science... and to show them that women in science can also have an impact with the research they are performing" [102].

Carolyn Bertozzi

(The Nobel Prize in Chemistry 2022)

Carolyn Bertozzi [108]

Carolyn Ruth Bertozzi is an American chemist known for her work spanning both chemistry and biology. Applying chemical synthesis to the study of biological systems, she coined the term "bioorthogonal chemistry" to describe the use of click reactions to study living cells. Carolyn Bertozzi demonstrated that these reactions could be carried out inside living cells to map molecules and cell function, without disturbing normal cellular chemistry [109]. These reactions are now used to explore cells, track biological processes, and improve the targeting of cancer pharmaceuticals [110]. The scientist makes an emphasis on studies of cell surface sugars called glycans important to human health-disease balance [111]. From a "bioorthogonal chemistry" perspective, Carolyn Bertozzi and her team discovered an as yet unknown cell surface sugar called glycoRNA. This approach is currently used to study molecules such as proteins, DNA and RNA in living cells. It is potentially useful as a drug delivery system for cancer treatment [112]. Carolyn Bertozzi's research has received the most prestigious recognition in the field of science: The Nobel Prize in Chemistry 2022 was awarded jointly to Carolyn R. Bertozzi, Morten Meldal and K. Barry Sharpless "for the development of click chemistry and bioorthogonal chemistry" [113]. When asked how she dealt with setbacks and remained patient, Carolyn Bertozzi responded: "Live in the moment", "if your goal every day is to try and contribute something and try to learn something new, … your chances of feeling successful are high because on any given day you'll learn something" [114].

Katalin Karikó

(The Nobel Prize in Physiology or Medicine 2023)

Katalin Karikó [115]

COVID-19 has changed the habitual way of life. Humanity has faced one of the greatest long-term threats: the new disease has caused physical health concerns and has had "monumental effects on the mental health and wellbeing of populations worldwide" [116]. Is there a way out of this abyss? And once again, a woman comes to the world's aid. Her name is **Katalin Karikó**. She is a Hungarian-American biochemist who specializes in ribonucleic acid-mediated mechanism, particularly in vitro-transcribed messenger RNA (mRNA) for protein replacement therapy [117; 118]. In collaboration with Drew Weissman, an American physician and immunologist, Katalin Karikó discovered that tRNA, unlike mRNA, did not provoke counterproductive immune responses in the body. This observation encouraged her and Weissman to experiment with modified nucleosides. The researchers identified associations between specific modified mRNA nucleosides and reduced immunogenicity. This discovery resulted in a technology known as non-immunogenic, nucleoside-modified RNA, which was developed and patented by Katalin Karikó and Drew Weissman [119]. These breakthroughs, coupled with the development of efficient in vivo mRNA delivery systems, the stabilization of the SARS-CoV-2 spike antigen, and unprecedented investments, culminated in the approval of two highly successful mRNA-based COVID-19 vaccines in late 2020 [120]. In 2023, the Nobel Prize in Physiology or Medicine was awarded jointly to Katalin Karikó and Drew Weissman "for

their discoveries concerning nucleoside base modifications that enabled the development of effective mRNA vaccines against COVID-19" [121]. Katalin Karikó had had to overcome many challenges before her work was recognized. However, she has never deviated from her courageous path lighting the way for the new generations of women in science.

Although there are extremely few women – Nobel Prize laureates today, there is still a positive trend. Since the first Nobel Prize was awarded in 1901 and until 2000, only 9 women have received the Nobel Prizes in Chemistry and Physiology/Medicine. As for the period from 2001 to 2023, 12 women have become Nobel Prize winners. Without any doubt, over the past century, ideas about a woman and her place in the society have changed dramatically. Organizations and programs that strongly support and encourage women on the thorny path of science play a major role in changing public consciousness. For example, each year, L'Oréal UNESCO for Women in Science national and regional programs represent more than 9 000 applicants, 52 country and regional programs in more than 110 countries [122]. The L'Oréal-UNESCO For Women in Science International Awards are presented every year to five outstanding women-scientists – one per each of the following regions: Africa and the Arab States, Asia and the Pacific, Europe, Latin America and the Caribbean, North America – in recognition of their scientific accomplishments. The scientific fields considered for the awards are life sciences, physical sciences, mathematics, and computer science. Seven laureates of the L'Oréal-UNESCO For Women in Science International Awards have also received the Nobel Prize in their field of expertise: Christine Nusslein-Volhard, Elizabeth Blackburn and Katalin Karikó in Physiology or Medicine; Ada Yonath, Emmanuelle Charpentier and Jennifer Doudna in Chemistry; and Anne L'Huillier in Physics [123]. The UNESCO Call for Action is "Closing the gender gap in science": "gender inequalities are so significant because they are deeply rooted in our societies. We cannot afford to waste any more time, and must act now to reverse these trends" [124]. Nowadays, more individuals, groups, organizations, and states are aware that gender equality in every sphere of life has a great potential to bring new perspectives.

Unfortunately, the dreams of bright minds about the realm of peace have never become reality, and our world is constantly shaken by wars, ethnic and religious conflicts, border clashes, let alone natural disasters. Many people are forced to leave their homes losing everything they are used to and "plunging into an ocean of uncertainty". Women-scientists are no exception. Not to mention the underrepresentation of women in science, even those who are able to realize their scientific potential in their home countries are being deprived of this opportunity, which is a serious loss for the entire global community. But fortunately, these women are not left out in the cold. The Institute of International Education's Scholar Rescue Fund (IIE-SRF) gives them a helping hand. IIE-SRF is the only global program that arranges, funds, and supports fellowships for threatened and displaced scholars at partnering higher education institutions worldwide, including inside their home regions [125]. As of January 2024, 1 093 scholars from 62 countries have received support from IIE-SRF. 1 777 awards have been granted, including renewals. Over $44 million in IIE-SRF fellowship grants has been approved by the IIE-SRF selection committee. 500 academic institutions in 56 countries across 6 continents have hosted IIE-SRF scholars [126]. Since 2002, IIE Scholar Rescue Fund has supported more than 20 female researchers and scientists in the field of chemistry and approximately 30 female researchers and scientists in the field of physiology or medicine. In 2023, IIE-SRF supported 67 women-scholars. The Institute of International Education has been providing assistance and support to threatened and displaced scholars for more than a hundred years, and among these scholars were: a German-born American physicist James Franck (the Nobel Prize in Physics 1925) [127]; a German biochemist Otto Meyerhof (the Nobel Prize in Physiology or Medicine 1922) [128]; a Swiss-American physicist Felix Bloch (the Nobel Prize in Physics 1952) [129]; a German novelist Paul Thomas Mann (the Nobel Prize in Literature 1929) [130]. And although there are no women-scientists on this Nobel list yet, we are sure that they will appear there in the near future. A Yemeni biochemist Eqbal Dauqan, who was an IIE-SRF fellow at the National University of Malaysia, said, "My dream is to win the Nobel Prize" [131]. In the meantime, an IIE-SRF alumna Marycelin Baba, a medical virologist from Nigeria, was awarded a medal of honor during the 25th L'Oréal-UNESCO International Awards ceremony for Women in Science [132].

In 2018, the "For Women in Science" prize as a part of the global L'Oréal-UNESCO program was established in Ukraine [133]. It is quite possible that

this award will be the first step on the way of Ukrainian women to the heights of science and recognition by the Nobel Committee. While Ukraine is 12th out of 41 European countries with one of the highest rates of women among all the scientists (45%) [133], our women – scientists and researchers have not yet gained recognition from the Nobel Committee. However, such powerful potential should not always go unnoticed. Today, the development of Ukrainian science should become a priority for both our state and society. And then the future Ukrainian Nobel Prize winners – women-scientists – will multiply the intellectual heritage of humankind [134]. The inspirational success stories about the women – Nobel Prize winners show that it is time to "unleash our full stature – our total brain power" [135].

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НАСТАВ ЧАС ВІДДАТИ НАЛЕЖНЕ ЖІНКАМ У НАУЦІ: ЖІНКИ, ЯКІ ОТРИМАЛИ НОБЕЛІВСЬКУ ПРЕМІЮ З ХІМІЇ ТА ФІЗІОЛОГІЇ АБО МЕДИЦИНИ

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У XXI столітті настав час визнати важливу роль жінок у науці. Дослідження, проведені жінками-науковцями поєднують світлий розум і глибокі знання з людяністю та мудрістю. Їхні підходи до вирішення проблем визначаються їхньою ментальністю та екзистенційним досвідом, що збагачує та розширює наукове поле. Це може призвести до несподіваних, але ефективніших вирішень. Проте жінки часто стикаються з перешкодами на своєму науковому шляху, і ситуація ще більш ускладнюється, коли йдеться про отримання наукових нагород, найпрестижнішою з яких є Нобелівська премія. З 1901 по 2023 рік Нобелівські премії присуджувалися 621 раз 965 особам і 27 організаціям, але лише 64 з них були отримані жінками-вченими. Хоча ми визнаємо та шануємо всіх жінок – лауреаток Нобелівської премії, у цій статті особливу увагу приділено жінкам, які отримали Нобелівські премії з хімії та фізіології або медицини і коротко описано їхні наукові досягнення. Більш детальніший опис їхнього життєвого та наукового шляху буде подано у наступних статтях.

Ключові слова: жінки-вчені, жінки-лауреатки Нобелівської премії, Нобелівська премія з хімії та фізіології або медицини.

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