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Grau de Química

Treball Final de Grau

Women's contribution to the periodic table. A proposal of learning activities in the Bachelor of Chemistry Degree.

Contribució de les dones a la taula periòdica. Una proposta d'activitats d'aprenentatge al Grau de Química.

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June, 2022

UNIVERSITAT DE BARCELONA

B:KC Barcelona Knowledge Campus
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La cultura no fa la gent. La gent fa la cultura. Si és cert que no forma part de la nostra cultura el fet que les dones siguin éssers humans de ple dret, aleshores podem i hem de canviar la nostra cultura.

Chimamanda Ngozi Adichie

M’agradaria començar donant les gràcies als meus tutors, l’Elisabet Fuguet i el Fermin Huarte, per donar-me l’oportunitat de poder escollir un projecte com aquest per acabar l’etapa universitària, així com per acompanyar-me durant tot el procés. Gràcies per fer-me creure en la importància d’aquest treball.

També m’agradaria donar les gràcies als meus pares, a la Sandra, als meus amics, i en especial, a l’Àlex per estar sempre al meu costat i per donar-me suport en els moments més difícils.

Finalment, vull fer una menció especial a totes les dones que han passat per la meva vida i m’han ensenyat a lluitar pel que vull. En concret, a la meva tieta i a la meva àvia, us estimo allà on estigueu.

REPORT

IDENTIFICATION AND REFLECTION ON THE SUSTAINABLE DEVELOPMENT GOALS (ODS)

The Sustainable Development Goals are a proposal to improve the society and the world in which we live. These SDGs can be grouped into five different spheres known as the 5Ps: people, prosperity, planet, peace and partnership. The project presented in this manuscript has its greatest impact on the “people” sphere, by giving visibility to the role of women in the periodic table, focusing on the eighteenth, nineteenth and twentieth centuries. In addition, based on this, educational activities have been created for chemistry degree students with the main objective of giving visibility to these women in the educational field and of making students reflect on issues related to gender. Furthermore, other topics on gender inequality have also been addressed, in particular how these women had problems to access to education or how they were affected by the social and historical context of that time.

This project could be developed further and focus on many other women who contributed to the development of the periodical system, both in the centuries described above and in the twenty-first century, in other words, in the present day. From this point, a full analysis of how the role of women in this field has evolved could be made: how much information is found on the latest discoveries in comparison to past discoveries, how many women have participated and what role they played, analyse whether the importance of the discovery prevails over gender, investigate the authorship of current scientific publications of these discoveries... From this project, it would be possible to show how certain aspects have changed or how they are maintained, and to make society aware of these realities, in large part to continue improving towards a society with gender perspective.

“Gender equality” is the main objective to which this project can be related. This is objective number five, which aims to achieve gender equality and empower all women. Two targets of this objective that can be specifically related to the present project. The first of these aims to "end all forms of discrimination against all women and girls everywhere" (target 5.1), and the second to "ensure women's full and effective participation and equal opportunities for leadership at all levels of decision-making in political, economic and public life" (target 5.5). Another issue mentioned is gender equality in education. That is why this project could also be related to SDG number four, which is "quality education". One of the goals to be achieved is the ease of access to education, both basic and higher, for women. For example, in 2016, out of 750 million adults (two thirds being women) were illiterate, largely from the third world. Within the goal of quality education, there are also different targets related to the aspects mentioned in this project. The first of these targets claims that "by 2030, ensure equal access for all women and men to affordable and quality education, including university" (target 4.3), and the second states that "by 2030, eliminate gender disparities in education and ensure equal access to all levels of education and vocational training for the vulnerable, including persons with disabilities, indigenous people and children in vulnerable situations" (target 4.5).

After proposing the different objectives and goals, I would only propose that just as there are targets in goal 4 that relate education to women, there should also be a target in goal 5 that relates women to education, and specifically, to science education. Today there is still gender bias in the field of science, technology, engineering and mathematics (STEM) in most of the world, and therefore, it is necessary for the scientific field to have equal opportunities without depending on gender.

- UNESCO [web]: UNESCO and Sustainable Development Goals. <https://en.unesco.org/sustainabledevelopmentgoals>

CONTENTS

1. SUMMARY

In a society where gender inequality is still present, it is crucial to fight for a change in the field of science, technology, engineering and mathematics (STEM). The first step is to give visibility to women who have made exemplary contributions to science. In particular, this project focuses on gender bias in the creation of the periodic table during the eighteenth, nineteenth and twentieth centuries, where women chemists and physicists played a very significant role.

In 1869, Dmitri Ivánovich Mendeleev published his version of the periodic table, which remains one of the most prominent representations in the world of chemistry. However, the periodic system was also the result of the collaborative work of many scientists who predicted and classified chemical elements before and after Mendeleev. Others discovered new concepts, such as isotopes, or simply introduced new techniques and proposals for the classification of new elements. The role of many women scientists who made very significant contributions to the study and search for new chemical elements is noteworthy. The two-time Nobel Prize winner Marie Curie is always renowned among female scientists, but unfortunately the history of science has ignored the paper of many other women scientists who made contributions to the periodic system, such as Marie Anne Paulze-Lavoisier, Jane Haldimand Marcet, Julia Vsevolodovna Lermontova, Harriet Brooks, Ellen Gleditsch, Lise Meitner, Stefanie Horovitz, Ida Tacke Noddack, Irène Joliot-Curie or Marguerite Catherine Perey.

Giving visibility to women researchers is one of the best ways to teach from an egalitarian point of view. For this reason, a set of educational proposals based on literature search have been created so that university students can reflect from a critical point of view and help to create a real image of the history of science, taking into account the historical and educational context.

Keywords: gender inequality, STEM, gender bias, periodic table, women scientists, history of science, give visibility to women, educational proposals.

2. RESUM

En una societat on la desigualtat de gènere encara continua estant present, és important lluitar per un canvi en l'àmbit de la ciència, tecnologia, enginyeria i matemàtiques (STEM). Per fer-ho, cal començar donant visibilitat a les dones que en el passat van contribuir de manera exemplar a la ciència. En concret, aquest treball se centra en parlar sobre el biaix de gènere en la creació de la taula periòdica durant els segles divuit, dinou i vint, on dones químiques i físiques van tenir un paper molt significatiu.

L'any 1869 Dmitri Ivánovich Mendeleev va publicar la seva versió de la taula periòdica, que actualment segueix sent una de les representacions més remarcables en el món de la química. Tanmateix, la taula periòdica no va ser obra d'una única persona, sinó que és fruit del treball de molts científics que van predir i classificar elements químics abans i després de Mendeleev. D'altres van descobrir nous conceptes, com per exemple els isòtops, o simplement van aportar noves tècniques i propostes classificatòries. Entre aquests científics destaquen el paper de moltes dones que van fer aportacions en l'estudi i la cerca de nous elements químics. Entre les dones científiques sempre és coneguda la guanyadora de dos Premi Nobel Marie Curie, però lamentablement la història de la ciència ha ignorat el paper de moltes altres dones que van fer grans aportacions al sistema periòdic com Marie Anne Paulze-Lavoisier, Jane Haldimand Marcet, Julia Vsevolodovna Lermontova, Harriet Brooks, Ellen Gleditsch, Lise Meitner, Stefanie Horovitz, Ida Tacke Noddack, Irène Joliot-Curie o Marguerite Catherine Perey.

Una bona manera de donar visibilitat a les dones científiques i que aquestes no quedin en un segon pla, és adaptant la docència des d'un punt de vista igualitari. Per això, en aquest treball, s'han creat una sèrie de propostes formatives basades en la cerca d'informació bibliogràfica, per tal que l'alumnat universitari reflexioni des d'un punt de vista crític sobre el veritable paper de la dona en la ciència, tenint en compte el context històric i educatiu.

Paraules clau: desigualtat de gènere, STEM, biaix de gènere, taula periòdica, dones científiques, història de la ciència, donar visibilitat a les dones, propostes formatives.

3. INTRODUCTION

For many years, women have played a very important role in science. Marie Curie (1867-1934) is the well-known figure of woman in the scientific world, but there are many other female chemists and physicists who have contributed and deserve a place in the history of science. Whether a woman could work in a scientific atmosphere depended on the cultural framework. The most important factors were the education received, social position, historical and political context, and social relations.

Women's work in the research field was made invisible and the names of those who contributed to a greater or lesser extent were rarely mentioned in the laboratory reports. In many cases, it was men who attributed their work to themselves. As a result, the books and articles on the history of science rarely highlighted the paper of women in science. This gender issue was synthesized in one concept: the Matilda effect [1,2]. This project focuses on women's contribution to the discovery of elements and the periodic system. In this way, Figure 1 shows women's contribution to the periodic table distinguishing between direct contribution (discovery of the element/related to it), indirect contribution (disclosure of the element) and a mixture.

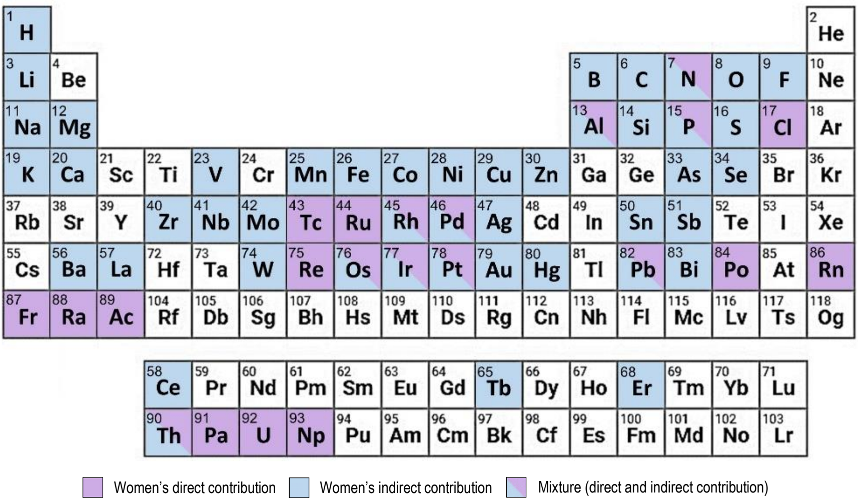


Figure 1. Representation of the women's contribution to the periodic table until the twentieth century.

This introduction is organised into three main parts. These three parts are the different time periods on which this project focuses, and specifically on the cultural, educational and scientific framework of each of the different time periods.

3.1. The *Révolution française* and the *salonnières*

The early years of the eighteenth century were remarkable for the Scientific Revolution, with the focus on France. It was a period of many discoveries and marked the end to alchemy. Alchemy was born as a supposed tool to find a way for transforming "inferior" metals to gold and to keep people away from illnesses and death. Although alchemists developed different instruments and established different experimental procedures, this pseudoscience had no logical basis. One of the landmark events of the Chemical Revolution was the dismissal of the "phlogiston" theory. Until 1780, it was mostly accepted that the formation of a calcium oxide from metal involved the loss of a material called phlogiston. It was believed that this substance was present in all the materials that could burn and was though to escape during its combustion. The conclusion reached was that phlogiston must have a negative mass. It was Antoine-Laurent Lavoisier (1743-1794) and Marie Anne Paulze-Lavoisier (1758-1836) who fought to prove that this theory was not correct. In 1783, he claimed that the oxidation involved the presence of oxygen, being a new gas discovered at the time, and not the loss of phlogiston. All these developments gave way to the "New Chemistry" [3].

During the mid-eighteenth century, France was ruled by Louis XV, and consequently by Louis XVI. This period corresponded to a time of active warfare, so economic conditions were not suitable. In addition, the government contracted a private company of tax-collection on its behalf. The person appointed to this task was called the *fermier* and his job was to collect taxes from agricultural households, land areas, different products… The problem was that many of these workers used their position to get money for their own benefit. During the period between 1789 and 1799, the *Révolution française* took place because of the economic, social and politico-ideological problems. The monarchy was abolished in 1792 and the Republic was proclaimed. Consequently, Louis XVI was executed in 1793 and all those who were related to the monarchy were punished and even killed, beginning the period of *la Terreur* [4].

Despite the beginning of a new era, the role of women was still greatly undervalued. The concept of "salon sociability" came back after the *Révolution française*. In the seventeenth century, the salons were created as centres for court ladies outside of royal commitments.

However, in the eighteenth century, at a time when women were not yet able to aspire to higher education, the concept changed into a space where class equality prevailed and as a focus to satisfy their own educational demands. The salons were used as an informal university for women to share ideas and to engage in literary and philosophical discussions. In short, it was a place to cultivate and learn in an indirect way. Salons were held in different parts of Europe, but France was the focus of the women who were interested in science. The women who were part of these institutions were called *salonnières* [5].

The period of *La Restauration* (1815-1830) began after the defeat of Napoleone Buonaparte at Waterloo that same year. Thereafter, the salons would begin to disappear from 1830 onwards, when the *Monarchie de Juillet* began. This disappearance was consolidated by a new elite that was supported by the clergy who wanted to enlarge the middle class. Therefore, they criticised upper-class women and the bad influence of the salons. Their ideology demanded a woman in the role of a housewife, based on obedience and dependence [3,6].

3.2. A NEW ERA FOR WOMEN'S EDUCATION

Few women could afford to work alone in research, since chemistry was a field that involved the use of equipment, reagents, books... Therefore, this expense could only be afforded by upper-class women. At that time, women were still not allowed to go to university. The focus of the Revolution shifted to Britain, where there were several prestigious chemists such as John Dalton (1766-1844), Joseph Priestley (1733-1804) and Humphrey Davy (1778-1829). During the first half of the century, there was an increase in the number of amateur women scientists, in part thanks to the popularisation of science by other women, both in books, as in the case of Jane Marcet (who attended Davy lectures), and in articles published in newspapers. At that moment, the professionalisation of female scientists started and later, the access to universities. However, before reaching that point, there was a long struggle behind. Until then, there was always the same dilemma as to whether it was better to educate a woman "like a man" or whether it had to be a home and childcare oriented education. Access to university depended on the secondary school leaving certificate. In French girls' schools Latin was not taught and therefore women could not do the *baccalauréat*. In the case of Germany, only men were allowed to take the university entrance examination. From about 1860 onwards, this began to change, and universities and colleges in Europe and the United States of America began to be open to women as well [3].

In the United States of America, higher education for women was allowed, but they wondered whether separate education or co-education was best. Women founded the Association of Collegiate Alumnae in 1881, concerned about this problem. The heads of the Wellesley College and the Bryn Mawr College were members of the association, but they had different positions on the best education for women. Bryn Mawr was an exclusive college for upper classes, so in 1885, most of the women who entered in the college were prepared in the best schools. There were other women’s colleges as Vassar (1865), Smith (1875) and Mount Holyoke Female Seminary (1837). At the same time, the colleges offering co-education were the Antioch College and Oberlin College, which were founded by liberal Christians. Most women preferred co-educational colleges because they knew the experience would be much better. In 1890, with 1082 colleges and universities, 43% were co-educational, 20% all-female and 37% all-male [7,8].

In 1870, there were British colleges affiliated to Cambridge University that allowed women to sit for university exams, but they could not obtain a degree until 1948. However, the University of London offered degrees to women as early as 1878, in co-educational institutions such as University College and the Royal College of Science, or in women's centres such as Bedford or Royal Holloway. In Germany, the first woman to go to university was in 1865 at the University of Munich. As German girls had problems attending high schools, foreign students were the main beneficiaries. Few women were awarded doctorates at that time, but Julia Vsevolodovna Lermontova (1847-1919) was one of the first to receive it. The best option for German female students was the University of Zurich as they were accepted there from 1860 onwards. In 1895, in Russia, women were allowed to attend scientific lectures. The arrest of a woman at a student demonstration was used as a restriction on women attending university, so Russian women went at the University of Zurich as well. Of 203 women at this university between 1864 and 1872, 148 were Russian. However, in 1873, the Russian government announced that the 103 women at Zurich had to return home or face total exile. This order was motivated by the belief that there was political and sexual radicalism at the university and the Russian government was against it [3].

While all this information is important to understand the lives of women scientists in relation to different parts of the world, the most important points were being part of the upper class with families that could afford a higher education. For poor women, going to university was unaffordable. Moreover, despite belonging to the elite of society, many families would be familiar with a conventional and traditional education. For some women, going to university also meant not having to get married at such a young age and not being always at home taking care of their children. Even so, having a career was not necessarily the consequence of not having a housewife's life. Another problem was the coexistence with men in mixed universities, some of whom did not support equality. The American Chemical Society, funded in 1876, and the Chemical Society of London, founded in 1841, created an atmosphere of discrimination against women, and it was not until 1920 that this changed [3].

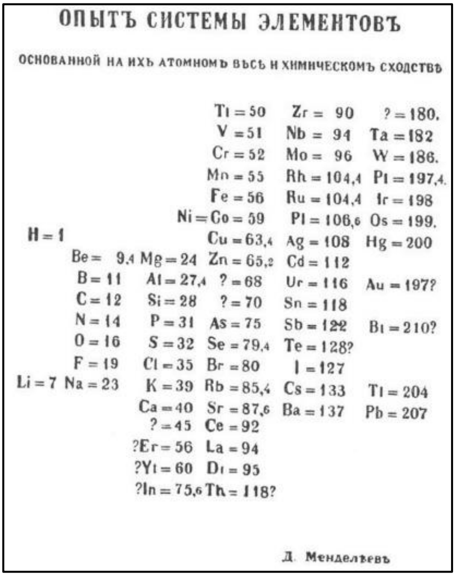
The period after the 1890s, when women had access to higher education and university, brought a new era of women. They usually had the opportunity to choose between family, a university degree or both. Thus, in the late nineteenth century and early twentieth century, marriage declined among women graduates. [9].

3.2.1. The periodic table until 1871

Nowadays, the periodic table is the most widely used tool and the most recognized icon of modern science. It is seen in books, schools, universities, on the internet… Not everyone is familiar with the periodic table, but it is well known for its importance in chemistry. However, how did it come to have this layout to capture the elements? We recognise the periodic table as a creation of Dmitri Ivánovich Mendeleev (1834-1907) in 1869. But in fact, he was not the first person to group different elements depending on their physical or chemical properties into a meaningful chart [10].

Over the ages, there has been an evolution of the concept of "element" and what was considered as such. The first existing and still known theory was to consider four elements: earth, fire, water and air. However, it was not until much later that the elements, as they are known today, would begin to be understood. Antoine Lavoisier, with Marie Paulze-Lavoisier, was the first to introduce the concepts of "*corps simples"*, listing thirty-three of them, and "*corps composés"*. He mentioned the fragmentation that a *corps composés* could undergo. John Dalton adapted the Lavoisier's theory, introducing the concept of "atomic weight". Then, in 1860, Jöns Jakob Berzelius (1779-1848) gave thirty different atomic weights values. In 1862, Alexandre-Emilie Béguyer de Chancourtois (1820-1886) recognised the periodicity in the elements and ordered the elements in increasing order of atomic weight. In 1864, Julius Lothar Meyer (1830-1895) introduced a periodic table in his book, but without a clear idea about the transition metals. He also predicted that elements not yet known could fill the vacancies in the table and noted the regular variation of valences according to periods. John Alexander Reina Newlands (1837-1898) noted a difference of sixteen atomic units between sets of different elements. These names are some of the most important ones that helped Mendeleev achieve his version of the periodic table [11].

In the first version, the elements are placed in columns and ordered by atomic weight from top to bottom as shown in Figure 2. In the version of 1871, the elements are listed horizontally in order of atomic weight and the groups in the vertical columns. Mendeleev used the prefix "eka-" to refer to a position below of an element [12].



ОПЫТЪ СИСТЕМЫ ЭЛЕМЕНТОВЪ

ОСНОВАННОЙ НА ИХЪ АТОМНОМЪ ВѢСѢ И ХИМИЧЕСКОМЪ СХОДСТВѢ

			Ti=50	Zr=90	?=180.
			V=51	Nb=94	Ta=182
			Cr=52	Mo=96	W=186.
			Mn=55	Rh=104,4	Pt=197,4.
			Fe=56	Ru=104,4	Ir=198
			Ni=Co=59	Pl=106,6	Os=199.
H=1			Cu=63,4	Ag=108	Hg=200
	Be=9,4	Mg=24	Zn=65,2	Cd=112	
	B=11	Al=27,4	?=68	Ur=116	Au=197?
	C=12	Si=28	?=70	Sn=118	
	N=14	P=31	As=75	Sb=122	Bi=210?
	O=16	S=32	Se=79,4	Te=128?	
	F=19	Cl=35	Br=80	I=127	
Li=7	Na=23	K=39	Rb=85,4	Cs=133	Tl=204
		Ca=40	Sr=87,6	Ba=137	Pb=207
		?=45	Ce=92		
		?Er=56	La=94		
		?Yt=60	Di=95		
		?In=75,6	Th=118?		

Д. Менделѣевъ

Figure 2. The first periodic table of Dmitri Ivánovich Mendeleev (1869) (07/06/22, *via Wikimedia Commons*).

3.3. RADIOACTIVITY AND THE EFFECTS OF THE WARS

The discovery of X-rays at the end of 1895 led to further research into other types of radioactivity. Scientists at the time claimed that there were many other types of rays, but it took a long time for this claim to be true. The first evidence of X-rays came from Wilhelm Conrad Röntgen (1845-1923) in Germany. Later, the French chemist Antoine-Henri Becquerel (1852-1908) observed the darkening of a photographic plate in contact with uranium salts, so X-rays were even called Becquerel rays. The interest increased in 1898, with the simultaneous discovery by Marie Skłodowska Curie (whose thesis supervisor was Becquerel) and Gerhardt Carl Schmidt (1865-1949) that thorium also emitted Becquerel rays. It was then that the nature of the rays and evidence of radioactivity in other elements was sought, and the search for radioactivity intensified. Curie began to use the term radioactivity to denote research in radiation physics and rejected the word "hyper-phosphorescence" used by Joseph John Thomson [3,13].

3.3.1. Women in radioactivity study centres

Several women scientists became involved in research in the new field of radioactivity in the early decades of the twentieth century. As a result, different "Schools" (institutions) were established as instates for the study of radioactivity.

At the *Institut du Radium* in Paris, also called the *Curie Institut*, women made up between 25% and 30% of the researchers between 1906 and 1934, when Marie Curie was its director. At this school, radioactivity was focused on the chemical part. Curie was a role model for many women scientists. However, she disliked working with students and preferred women to accept the values and practices of men rather than fight for discrimination against women. In fact, she got along better with her male colleges and students than with the women scientists of the time. Harriet Brooks (1876-1933) worked at the *Curie Institut,* and Ellen Gleditsch (1879-1968), Irène Joliot-Curie (1897-1956) and Marguerite Catherine Perey (1909-1975) worked as Marie Curie's assistants. André-Louis Debierne (1874-1949) and Irène Joliot-Curie, Marie Curie's daughter, took over the direction of the Institute when Curie died in 1934 [3,13].

Ernest Rutherford (1871-1937) was the leading figure at McGill University in Montreal. He worked with the chemist Frederick Soddy (1877-1956), with whom he proposed the theory of radioactive disintegration. Rutherford was interested in the physical and chemical aspects of radioactivity. He began his career at the Cavendish Laboratory in Cambridge. This laboratory had been open to women since the 1880s, when most of them excluded women scientists. Rutherford was always an advocate for women, believing that they were part of the laboratory and that both genders could work together peacefully. However, there were no female staff in Cambridge during the twenties. He mentored many young students, as Harriet Brooks, that was his first graduate student at McGill University. Otto Hahn (1879-1968) and James Chadwick (1891-1974) also worked with Rutherford, the former in Montreal and the latter in Cambridge. He also worked at the University of Manchester with Hans Geiger (1882-1945) and again with Brooks [13].

In Vienna at the beginning of the twentieth century, there were two centres dedicated to nuclear research: the Second Institute for Physics of Vienna University and the *Institut für*

Radiumforschung. The *Institut für Radiumforschung* (also called The Radium Institute or Vienna School) was founded in 1910 and headed by Stefan Meyer (1872-1949). He was a man of great kindness and had a great impact on the women scientists who passed through the Institute. Additionally, between 1919 and 1934, there were 43 women among 113 staff members. Meyer was a physicist, so he made emphasis on the nature of the rays. At that time, Austria was the largest source of radioactive minerals and the Vienna Institute had the best access to radioactive materials. In concrete, it was thanks to the St. Joachimsthal mine in Bohemia, which was part of the Astro-Hungarian Empire. This mine was very important to Marie Curie and Pierre Curie (1859-1906), as it provided them with the raw material, they needed to isolate large quantities of the new elements. Meyer was the mentor of Ellen Gleditsch and Lise Meitner (1878-1968). Stefanie Horovitz (1887-1940) also worked in the Vienna School with Otto Hönigschmid (1878-1945) [13].

3.3.2. The consequences of the wars

After the First World War (1914-1918), the disintegration of the Austro-Hungarian Empire caused many of the Vienna Institute's students to go elsewhere, especially to Germany, where the Kaiser Wilhelm Institute for Chemistry (1912) in Berlin-Dahlem was to become a new focus. At that point, only 13% of the students at the university were women. Moreover, in the 1920s, the St. Joachimsthal mine was then part of Czechoslovakia. In the *Laboratorium Hahn-Meitner* at the Kaiser Wilhelm Institute, between 1912 and 1938 there were 14% of women [13].

The proportion of women entering most institutions to work in the field of radioactivity declined, and those who did, worked as technicians. For example, Soddy attended many female students in his classes at the University of Aberdeen, in Scotland, before the First World War. However, there was a decline by the 1920s, clearly visible in the period 1917 to 1918, probably because of the war. Discrimination against women increased and beliefs in a traditional role for women re-emerged. Before the First World War, women were tolerated in the "male-occupied fields". However, during the war period, many women occupied the men's professions, as many of them had left their jobs to fight in the war. In the post-war period, although women proved to be able to work on equal terms, many of them were fired from their jobs [14].

The United States of America became a centre of focus on radioactivity, but women were not encouraged to enter, as in the case of Gleditsch with Yale or Harvard University. This attitude continued even into the 1940s and 1950s, with women playing a secondary role in the

Manhattan Project. Around 1980, there was still an aggressive and competitive behaviour towards women [14].

In Austria, the high proportion of women was remarkable, which could be related to the political and social environment of Red Vienna in the 1920s and 1930s. However, in 1938, the *Anschluss* of Austria to Nazi Germany took place. This political change also brought changes at the Institute: a quarter of the Austrian nuclear researchers lost their jobs, just for being Jewish, and the number of women working there was halved by the end of that year. At the University of Vienna, there were two vacancies for professorships and two vacancies for associate professorships, which were filled by academics who followed Nazi beliefs. Gustav Ortner (1900-1984) took the place of Stefan Meyer (1872-1949), who had to leave the position because he was a Jewish heir. In 1943, still during the Second World War, the Second Institute for Physics and parts of the Radium Institute merged to create the Four-Year-Plan Institute for Neutron Research. Before this institution was founded, nuclear fission was already a subject of interest to many Austrian physicists, and the Germans' uranium club opened new doors for research. All German projects related to uranium fission were organised in the club from 1939 to 1945, where its central project was to create a nuclear reactor during the war [13].

3.3.3. Scientific context of new discoveries

In the early twentieth century, scientists predicted the existence of more than thirty new elements. Chemists of the time had assumed that atomic weights were a fundamental property of each element, but the British chemist Frederick Soddy proposed that atoms of the same element could differ in their atomic weight. Although Soddy introduced the concept, it was Margaret Todd (1859-1918) who suggested the name "isotope" meaning "same place" in Greek. Furthermore, Ellen Gleditsch and Stefanie Horovitz helped to prove the existence of isotopes. Then, between 1912 and 1913, Frederick Soddy and Kasimir Fajans (1887-1975) published the ideas about the "Group Displacement Law", which permitted scientists to predict the positions of unknown elements. This law explained that "an alpha emitter would decay into an element two places to its left in the periodic table and have an atomic weight of four units lower, while beta emitter would transmute into an element one place to its right in the periodic system and preserve its atomic weight". Later, in 1934, Enrico Fermi (1901-1954) and his collaborators were the first to obtain elements heavier than uranium by bombarding uranium nuclei with neutrons.

These elements were 93 and 94, which they called “ausonium” and “hesperium”. However, Ida Tacke Noddack, Lise Meitner and Irène Joliot-Curie repeated his experiments to determine that he was not in the right position, and furthermore, they used his research to make new discoveries [15].

3.4. EDUCATION DURING THE TWENTIETH CENTURY

At Mount Holyoke College in Massachusetts, the courses with the highest number of female students were during the academic years 1911-1912, 1914-1915, from late 1918 to 1935, and from late 1927 to 1930. Patterns were repeated in the same years at other colleges such as Bryn Mawr, which had high female employment from 1914 to 1916 and from 1919 to 1922. In the Wellesley College it was during 1919, 1922 and 1927. Traditionally physics had more female students than chemistry, although a change was observed at the beginning of the twentieth century. At the University of Wisconsin-Madison, a co-college, women occupied the 22% of chemistry classes in 1920, the 10% in 1925 and the 13% in 1929. Furthermore, in the United States of America, there was a decline in women chemists earning doctorates after 1932. In 1929, 10% of chemistry doctorates were awarded to women and in 1933 5%, reaching a level as low as 2% in 1940. A 10% returned in 1946 but was not surpassed until 1972. In addition, in the 1920s, women earned 12 out of 100 awards, with the highest rates until 1975. Women’s higher education was 21% in 1870, 36% in 1890 and 47% in 1920. In Canada, the decline of women in "male-occupied fields” was during the 1920s and 1940s. The reason is not known, but women realised that with a science-related degree they would not have many job opportunities. However, a degree with an educational or social aspect might have more possibilities, such as teachers, nurses, domestic servants, saleswomen… Discrimination against women was also visible, as during the 1930s scholarships were especially for men. For example, at the University of Alberta, the hatred was so strong that the Woman-Hater's Club was elected as president of the student union. This anti-feminist attitude could not only be observed in Canada. In Italy, there was also this hostile attitude against women in the universities. The government was another precursor of this hate, and placed restrictions on women during the inter-war period. In Germany, under Nazi rule, a law was enforced in 1934 that required female high school graduates to work as a *Arbeitsmaiden* (a six-month labour service) before they could apply to university. This law was passed as a first obstacle for women who wanted to go to university [14].

4. OBJECTIVES

The first objective of this project is to analyse the role of women in the periodic system, in terms of their significant contributions to the discovery and study of the elements that shape the periodic table. The aim is to point out the importance of the role of women in science and to give visibility to the figure of these women whose roles were overshadowed by the position of men.

To achieve this objective, it is necessary to highlight the background of the lives of each of the women mentioned, especially the historical, social and educational background.

The second objective is to propose a set of learning activities to stress the contribution of women in the periodic table in the academic world. Students are expected to express their ideas and opinions in some activities proposed for the subject of Chemical Documentation (located in the fifth semester of the Bachelor of Chemistry Degree), using the SciFinder database as a tool for searching and analysing the desired information.

5. THE ROLE OF WOMEN IN THE PERIODIC SYSTEM

5.1. EIGHTEENTH CENTURY

5.1.1. Marie Anne Paulze-Lavoisier (1758-1836)

Marie Anne Pierrette Paulze was born the 20th of January 1758, in the Loire province, in France. She was the daughter of Jacques Paulze and Claudine Thyonet, a bourgeois family. Her father was the head of the *Ferme-Générale*. When she was only three years old, Claudine Paulze died, and Marie Anne was raised in a convent. At the age of thirteen, Count d'Amerval, a fifty-year-old influential man, decided he wanted to marry her. Her father disagreed with this forced marriage, so he proposed to Antoine-Laurent Lavoisier, one of his colleges, to marry his daughter. Finally, they married in 1771 [16].

After the wedding, Marie Anne became very interested in the research of her husband and in the laboratory work. Jean-Baptiste Bucquet (1746-1780) and Philippe Gingembre (1764-1838), two friends of Lavoisier, were responsible for teaching her about chemistry. Paulze-Lavoisier had also an interest in art, so she studied it with Jacques-Louis David (1748-1825). Mainly her task was to write all the work Lavoisier did in the laboratory. In addition, she wrote different publications about phlogiston and engraved thirteen plates in her husband's book *Traité élémentaire de chimie* (1789), which can be considered the first text of modern chemistry. Marie Anne drew the equipment that Lavoisier and his friends used in the laboratory: flasks, funnels, mortars… She signed her work preserving her maiden name. The Lavoisiers were in the laboratory between six and nine in the morning, and then between seven and nine in the evening. Part of their routine was doing their own parties, where they invited local and foreigner scientists (and high society people) to their house. Among the guests there were Benjamin Franklin (1706-1790), who had a very close relation with Lavoisier, Joseph Priestly, James Watt (1736-1819) and Arthur Young (1741-1820). At these parties and meetings, they promoted the "New Chemistry". In fact, the couple were able to work, learn and have a social life as they had no children and Lavoisier's aunt, who looked after him, took care of the house [3,17].

Another important characteristic of Paulze-Lavoisier were the languages, especially English and Latin, but also Italian. She was involved in translating lots of texts to French, the most important ones *An Essay on Phlogiston* (1787) and *Of the Strength of Acids* (1791), both written by Richard Kirwan (1733-1812). At the same time, she added her own footnotes indicating errors in the chemistry of the book. Thanks to her, Lavoisier and his colleagues could understand and respond to Kirwan's arguments and overturn the theory. However, in the publication of *Essai sur le phlogistique* (1788) her name didn't appear as the translator of the book. Paulze-Lavoisier also translated J.Priestley and Henry Cavendish (1731-1810) works, as far as others for Lavoisier's personal use [15].

In 1794, Antoine Lavoisier and Jacques Paulze were executed for belonging to *Ferme-Générale*. Marie Anne made sure that Lavoisier's work *Mémories de chimie* was brought to light. The first volume talked about their work on heat and the formation of liquids and the second, dealt with combustion, air, calcination of metals, acids and water's composition. In this book, he recollected all the papers of his research work and some of his colleagues. For the publication of the book, Paulze-Lavoisier asked to her friend and co-author, Armand Seguind (1869-1903), to write a preface against the revolutionaries who were the responsibles of

Lavoisier's death. He refused to do so, and it was Marie Anne who wrote it and ensured that the book's binding and publication process could be carried out. The printer was Pierre Samuel du Pont de Nemours, who had a friendly relationship with Lavoisier since 1776 [3,18].

Du Pont borrowed Lavoisier's funds to carry out the printing of the book. Then, du Pont was imprisoned and could no longer repay to the widow. At the same time, Paulze-Lavoisier's belongings and finances were seized. After being imprisoned during sixty-five days, she demanded du Pont to return all the money. Finally, the conflict was resolved and the printing of the book was completed. That same year it was sent to all the crucial scientists of the moment. From then on, Marie Anne attracted many suitors, most notably Benjamin Thompson (1753-1814), who called himself Count Rumford. He was one of the most important physicists of the time and was engaged in the research into heat being a material substance called caloric. In 1805, Rumford and Paulze-Lavoisier got married, and although they knew each other for four years and had travelled around Europe, the marriage worsened within the first two months. Rumford was only looking for money to fund his independent laboratory and Paulze-Lavoisier wanted to be part of that research. This bad relationship became public knowledge in Paris, and they divorced in 1809. She never returned to laboratory work and instead, she dedicated to charity work [3].

Many of the contributions that Marie Anne Paulze-Lavoisier did during her life were with Antoine Lavoisier. It is known for sure that she was her laboratory and library assistant, collaborator, scientific partner, painter, editor and the translator of the books and scientific papers. As a result of their close relationship, it is difficult to identify if she did her own contributions to science but is commonly accepted that much of their work is credited to him. Together, they disapproved the idea of phlogiston and introduced the phenomenon of combustion; they developed the law of conservation of mass; studies of transpiration and respiration; and were very important in the development of the periodic table, listing thirty-three elements. These elements were: light, matter of fire (caloric), oxygen, hydrogen, carbon, sulphur, phosphorus, sixteen previous known metals, organic radicals and the alkaline earth oxides and alkali metal oxides (nowadays decomposed into alkaline earth metals, alkali metals and oxygen) [15,18].

5.2. NINETEENTH CENTURY

5.2.1. Jane Haldimand Marcet (1769-1858)

Jane Haldimand was born the first of January 1769, in London. She was the eldest daughter of a wealthy Swiss-English family. At the age of fifteen, her mother died and she took charge of a large family. Jane started working as her father's assistant, who was a merchant banker. Jane was home-schooled with her siblings, being taught the same subjects as her brothers (chemistry, biology, history and Latin) and art, music and dancing, that were specifically for girls. At the age of seventeen, she travelled to Italy to develop her artistic knowledge. In 1799, being thirty years old, she married Alexander Jean Gaspard Marcet (1770-1822), a physicist who was born in Geneva. The couple had two sons, one of whom died in his teens, and two daughters. Marcet was fellow of the Royal Society of London and a lecturer of medical chemistry at Guy's Hospital. Because of that, he was part of a circle of important people, including scientists, writers and economists. Among his circle of scientific colleagues there were Jöns Jacob Berzelius, Humphry Davy, William Wollaston (1766-1828), John Dalton, Smithson Tennant (1761-1815), Charles Hatchett (1765-1847) and Michael Faraday (1791-1867). Being in contact with this people meant they were always up to date with the new scientific developments [19,20].

Jane Marcet started to perform her own research and this made her learn a lot about science. In fact, she noted down everything she did and started to write the introduction of a book that would help particularly to the female sex. In the first edition, the author is uniquely identified as "a lady" and "with no real claims to the title of chemist" but clarifying she had received the help from a friend, which now we know to be her husband. This book was called *Conversations on Chemistry, in which Elements of Science are Familiarly Explained and Illustrated by Experiments* (1806). Evidently, she did it in a very familiar and approachable style that could help other women feel confident and understand chemistry more easily. The book was written like a story between a teacher, named in the book as Mrs B., and two students, named Emily and Caroline. Emily is serious and hard-working, and Caroline is more spontaneous and imaginative, so there are two completely different profiles of women. The two students are between thirteen and fifteen years old. Mrs B. identifies herself as Mrs Bryan. At the time, there was a female scientist with two daughters called Margaret Bryan and it is possible that Marcet used this name to trick people into thinking she was the one who wrote the book anonymously. Or there could be the possibility that she based on Emily and Caroline Sebright, daughters of Sir John Sebright, a Marcet's friend. The book has twenty-six conversations. In the first one, she introduces the concept and definition of the elements and their classification, where she talks about light and calories (heat substance) which appeared in Lavoisier's table of the elements of 1789. The conversation number six talks about oxygen and nitrogen, the seventh about hydrogen, the eighth about sulphur and phosphorus, the nineth about carbon and the tenth about metals and their reactions [21,22] .

Undoubtedly, the book was extremely successful and went through eighteen editions in Britain, the first in 1806 and the last in 1853. Therefore, the publications were made anonymously for fear of losing her reputation and it was not until the 13^{th} British edition in 1837 that her name appeared as the real author. Marcet's book became very popular in America. The first edition of 1806 was called *Conversations on Chymistry* and it had two volumes. There were twenty-three printings in America between 1806 and 1850, with 160.000 copies. Additionally, there were four French editions in Paris, a Swiss edition in Geneva and an Italian translation of the French edition. Jane Marcet published other books that were not in relation with chemistry. All of them starting with "Conversations on…": *Conversations on Political Economy* (1816), *Conversations on Natural Philosophy* (1819) and *Conversations on Vegetable Physiology* (1829) [3,23].

In her later publications, Marcet would add the latest discoveries of famous British scientists, as the case of Dalton or Humphrey Davy's isolation of the alkali metals, potassium and sodium. Marcet had many other friendships with scientists who at the time had discovered new elements, such as J.J. Berzelius (Ce, Th, Se, Si, Zr) and his students (Li, La, Er, Tb, V), W. Wollaston (Rh, Pd), S. Tennant (Os, Ir) and C. Hatchett (Nb). Before 1869, when Mendeleev did the publication of his periodic table, five new elements were discovered, having at that time sixty-three elements. However, she followed the configuration and classification of the table proposed by Lavoisier [15].

Jane Marcet's knowledge came from the lectures she attended at the Royal Institution, her contact with London and foreign scientists, her marital relationship with Alexander Jean Gaspard Marcet and privileged access to books and information about science. Even though all these factors worked in her favour, in Alexander's private notebooks, it can be corroborated that Jane Marcet did not write the book entirely on her own, as her husband helped her in the realisation of it. Jane Marcet died at the age of eighty-nine in London. Thanks to Marcet's book, it was possible for many schools to teach science or chemistry as subject and to reach all audiences. It was possibly the best seller chemistry book in English of the first half of the nineteenth century [3,19].

5.2.2. Julia Vsevolodovna Lermontova (1847-1919)

Julia Vsevolodovna Lermontova (Figure 3) was born the 2nd of January 1874, in a wealthy family in St. Petersburg being the daughter of Elisawjeta Andrejevna Kossikovsky and the General Vsevolod Lermontov. When she was a child, they moved to Moscow where her father was in charge of the Moscow Cadet Corps. It was him who looked for the best instructors to educate his daughter in their own home, giving her the freedom to develop her knowledge in chemistry. At the age of twenty-two, Lermontova was rejected from the Moscow's Petrovskaia Agricultural College, so she decided that the most effective way to continue her education was to leave the country. After getting her parents' permission, she left for Heidelberg University in Germany, where she would stay with the mathematician Sofia Vasilyevna Kovalevskaia (1850-1891). Kovalevskaia became the first female professor to teach mathematics worldwide. Although she arrived at the university in 1869, she could only attend lectures without being able to graduate. Lermontova received permission to attend lectures and to work in Robert Bunsen's (1811-1899) laboratory, where she studied qualitative and quantitative analysis [16,24].

Figure 3. Portrait of Julia Vsevolodovna Lermontova (07/06/22, *via Wikimedia Commons*).

In 1870, Anyuta (Kovalevskaia's older sister), Evreinova (Lermontova's cousin) and Julia created a women's group called "Heidelberg women's commune". The concept spread to different academic centres in Europe and helped to support women with a similar situation as them [3].

Between 1870 and 1871, Julia Lermontova and Dmitri Mendeleev met each other. During the following years, they wrote letters to each other about the separation of the platinum group. Mendeleev was very interested in the precision of the atomic weights for these six metals: ruthenium (Ru), rhodium (Rh), palladium (Pd), osmium (Os), iridium (Ir) and platinum (Pt).

Lermontova started the separation process, where she analysed two samples: one rich in Pt that also contained Pd, Ir and Rh and another second sample that contained all the metals except for Os. This was important to investigate which compounds were insoluble in water or other solvents. Firstly, ruthenium was separated as $Ba[RuCl_6]$. The other metals were transformed into chlorides and precipitated in the order of Pt, Pd, Rh and Ir. After the research, she described the process, but she never gave specific information about the colours of the precipitates or quantitative information. Lermontova did not give values of the atomic weights for the platinum group, but the separation of these metals was an important prerequisite for the correct values. The description of the separation procedure is the one used nowadays. Her idea was to analyse a third sample for the research on the separation of the platinum group, but she moved to Berlin with Kovalevskaia and abandoned the field of platinum metals. In Berlin, Lermontova attended lectures by August Wilhelm von Hofmann and worked with him in his private laboratory on diiodomethane [3,15].

In that point, Lermontova and Kovalevskaia could already pursue a doctorate, but neither Heidelberg nor Berlin could offer them the university degree. After many objections, Weierstrass succeeded in getting them to the University of Göttingen and in 1874, they both received their doctorates. Lermontova returned to Russia the same year, where she began working at the University of Moscow with Vladimir Vasilyevich Markovnikov on the synthesis of 1,2-dibromine propane and glutaric acid. In 1875, Lermontova became the second female member of the Russian Chemical Society. The relationship with Sofia was so close that Julia became the godmother of her daughter Sofia Vladimirovna (who they called Fufa). Lermontova fell ill with typhoid fever and had to retire for a year. When she recovered, she went to St. Petersburg to work with Aleksandr Mikhaylovich Butlerov, with whom she studied the catalytic reaction between tertiary butyl iodide and isobutylene. From 1876, Lermontova worked in *Bulletin de la Société Chimique de Paris* as a correspondent. However, at the peak of her career, she had to return to Moscow to help Kovalevskaia in her financial problems. Although Butlerov insisted that she stayed, she left. In 1880, together with Markovnikov, they investigated the composition of the Caucasian oil. He proposed to her to work on high-pressure cracking of hydrocarbons in the presence of metals. During the research, she developed an apparatus for the continuous distillation of oil. In that moment, this was a huge technological breakthrough, as until then, crude oil had been processed by batch treatment. In 1881, Julia became the first women to be a member of the Russian Technical Association [3,15].

Later, she was invited to supervise the practical courses of chemistry at the Higher Courses for Women in St. Petersburg, but Lermontova refused it. According to Lermontova, she was not sure that the Ministry of Education would accept her because she did not have Russian scientific degree. But according to Butlerov, the reason was that while Kovalevskaia travelled around Europe in search of an academic position to develop her mathematical work, Lermontova took care of Fufa. In fact, from 1883 onwards, Fufa lived with Julia [15,16].

Lermontova settled permanently into a farmhouse in Semenkovo. She continued doing scientific work but focusing on large-scale cheese-making. When Sofia died in 1891, she left the full custody of Fufa to Julia. Lermontova died in 1919 because of a brain haemorrhage. Sofia Kovalevskaia had an international recognition, however, Julia was only acclaimed by the people who surrounded her [3,16].

5.3. TWENTIETH CENTURY

5.3.1. Marie Skłodowska Curie (1867-1934)

Marie Curie (Figure 4) was born the 7th of November of 1867, in Warsaw, Poland, as Marya Salomea Skłodowska. Marya was the last of five siblings. Her parents were called Władyslaw Skłodowski and Bronisława Boguska. Her father was a physics and mathematics teacher of the *Lyceum* and her mother the director of a girls' private school. In 1795, Poland was divided between Germany and Russia, and the Skłodowski family belonged to the Russian-controlled side. However, the family had Polish nationalist beliefs, so Władyslaw Skłodowski was always fired from his jobs. In addition, Marya's mother had tuberculosis and she never had physical contact with her for fear of passing the disease to her daughter. Sadly, being only a child, Marya's older sister died of typhus, as did her

Figure 4. Marie Curie working in a laboratory (Vitold Muratov, 07/06/22, *via Wikimedia Commons*).

mother, who died of tuberculosis. This meant a hard childhood for Marya, and these tragedies marked her character and personality [25,26].

At that moment, Russia did not allow women to go to the university, so she made a pact with her sister Bronisława (Bronya) in which they promised mutual financial help to study in Paris. Marya started to work as a servant in a rich family and she established a close relationship with the family's eldest son. However, they did not want him to marry her because she came from a poor family. Although Bronya insisted Marya to go to Paris, she did not have enough self-confidence, and she returned to Warsaw with her father, where she attended the "underground" Polish university. Finally, in 1891, with enough money to support herself, she decided to go to Paris. In that moment, she changed her name from Marya to the French Marie. Marie began studying at the *Faculté des Sciences*, in *La Sorbonne*. Marie obtained a master's degree in physics in 1893 and then she graduated with a degree in mathematics in 1894. That same year, Marie began to work in a project for the development of national industry, where she met Pierre Curie, a professor at the *École Supérieure de Physique et de Chimie Industrielles de la ville de Paris* (ESPCI Paris). They married in 1895 and then, the Curies began to work together in a laboratory in Paris. In 1897 their first daughter, Irène, was born, and Eugène Curie, Pierre's father, took care of his granddaughter [3,17].

After the birth of her daughter, Marie Curie decided to start research for a doctorate in science at *La Sorbonne* to investigate the X-Rays. Marie's research was carried out at the ESPCI with the collaboration of his husband Pierre Curie. Firstly, Marie examined different samples of metals and alloys that emitted the Becquerel rays. Moreover, she studied the collection of the minerals of the school and different samples of metals, salts, oxides and minerals from museums, such as pitchblende, uranium ores and chalcolite. Marie Curie changed the method using an electrometric equipment that Pierre and his brother used during the discovery of piezoelectricity, in concrete, a sensitive gold-leaf electroscope. The samples were placed in a chamber in which electric voltage was applied and the values of the ionisation current were measured. The samples were classified as current-producing or not [15,17].

In February 1898, Marie Curie observed that two samples of uranium minerals, pitchblende and torbanite, showed a higher radioactivity than pure uranium. In a paper published in April 1898, Marie said that she hypothesised that the minerals contained an element much more active than uranium. With the help of Pierre Curie and their co-worker Gustave Bémont (1857-

1937), Marie began to isolate this new element. After six months of research, they extracted a precipitate that was four hundred times more radioactive than uranium. In a paper published in July 1898, they concluded that it was a new metal, which Marie Curie named “polonium”, in honour of her birthplace, and the word “radioactive” appeared for the first time in reference to a property in which matter spontaneously emitted radiation. However, neither a pure sample nor any chemical properties were available. The identification of polonium was due to its differentiation from other metals. Moreover, polonium behaved in a very similar way to bismuth, which made it difficult to distinguish between them [15,27].

While extracting the polonium, the Curies and Bémont obtained a precipitate of barium that was very radioactive. They argued that the precipitate contained a radioactive element like barium. This new radioactive material did not precipitate with hydrogen sulphide, ammonia and ammonium sulphur, but its sulphate and carbonate were water insoluble. Later, they realised that its chloride was less soluble in aqueous alcohol solution than that of barium. The pitchblende was very expensive, so the Curies obtained it from the mine at St. Joachimsthal. In December 1898, they announced the discovery of a new highly radioactive element which they called “radium”. Eugène-Anatole Demarçay (1852-1903), who was an expert spectroscopist, identified a new line that could not be correlated with any other element. At that point, the Curies found a “new” way to discover different radioactive elements, but to convince the scientific community it was necessary to produce larger amounts and establish the atomic weights of these new elements [3,15].

In November 1903, the Swedish Academy of Sciences proposed the names of Henri Becquerel and Pierre Curie as candidates for the Nobel Prize in Physics for their work on radioactivity. Later, Marie Curie was nominated with them. Eventually, they won the Nobel Prize, but the Curies were too ill to collect the prize, so it was not until 1905 that Pierre was able to travel to Stockholm to receive it. Marie Curie was the first woman in history to win a Nobel Prize. After this moment, the Curies’ life changed completely and their fame increased enormously. On the one hand, Pierre received the professorship at *La Sorbonne* and became a member of the *Academie des Sciencies*. On the other hand, Marie went from lecturer to teacher at the women teacher’s college at Sèvres. A laboratory was built for Pierre, and Marie Curie was given the position of head of laboratory. With the money they received from the Nobel Prize and the other awards, they helped by providing scholarships to Polish students and sending money to their family members. In December 1904, their second daughter Evè was born [27,28].

On the 19th of April 1906, Pierre died in a street accident. As already mentioned, Pierre was ill for a long time before his death and his disease was probably caused by the long exposure to radioactivity. The first of May 1906, *La Sorbonne* offered Marie a position as an assistant professor, being the first woman professor in the university. Two years later she became full professor. During the following years Marie Curie had to face with certain problems. In 1910, it became public the Marie's affair with Paul Langevin (1872-1946), who was a physicist and a close friend of the Curies. However, in 1911, Marie was proposed for membership in the *Academie des Sciencies* and was awarded with the Nobel Prize in Chemistry, in recognition of her work on polonium and radium [28,29].

When the First World War broke out, male scientists and laboratory workers were recruited to fight. Marie stopped her job in order to bring "radiology cars" from hospitals to the front lines. For Curie, it was very important to find a use for radioactivity in the medical field. In 1915, there were requests for radium therapy (called "curietherapy") for treating a wide range of diseases, including different kinds of cancer. Marie and Irène worked together as X-ray technicians until 1916. When the government realised the importance of these devices, they were asked to train physicists and technicians to operate these units. By the end of the war, the X-ray machines would have examined more than a million soldiers. After the war, *the Institut du Radium* was inaugurated with two buildings, one to provide space for Marie's research group and another for the medical, led by Claudius Regaud (1870-1940). By 1931, there were thirty-seven researchers in her charge, of whom twelve were women [3,28].

In 1921, an American journalist, Marie Mattingly Meloney organised a trip to the United States of America for Marie, Irène and Evè. They gave a false image about Curie's life, making people believe that she did not have enough money to support the *Curie Institut*. Thanks to that, Marie was awarded with prizes of twenty different American universities and even had a reception with President Harding. She made another trip in 1929 after the success of the first. Between these two trips, Curie suffered four cataract operations, being one of the symptoms caused by radioactivity. In fact, one of her laboratory researchers, Sonia Cottelle, died after ingesting a polonium solution. Moreover, there were other Curie workers who died prematurely. Marie Curie never admitted that radiation was dangerous, despite the deaths and illnesses. Before her death, Marie destroyed many of her personal papers, in particular those from the period of her relationship with Langevin. Marie Curie died at the age on sixty-seven, supposedly of aplastic anaemia, but it is now known to have been a secondary effect of leukaemia caused by radiation [3,30].

5.3.2. Harriet Brooks (1876-1933)

Harriet Brooks was born the 2nd of July 1876, in Exeter, Ontario. She was the third child of nine children. Her father, George Brooks, was a flour commercial traveller. Her mother's name was Elizabeth Worden. Because of her father's job, they had to move regularly. Brooks wanted to attend university and, in that moment, they were living in Quebec, Canada. At the age of eighteen, she was accepted at the Royal Victoria College, which was only for women, being part of McGill University. Brooks graduated with Bachelor of Arts in Mathematics and Natural Philosophy in 1898.

Harriet Brooks was an exceptional student and after her graduation, Ernest Rutherford invited Brooks to be his graduated student researcher. Brooks was assigned a project about "emanation". Rutherford named this concept to a material given off by thorium. Brooks' work showed that emanation was a gas, that a gaseous specie could be produced from solid, and that it had a measurable weight. This gas is now known to be radon. At the time it was believed that radioactive elements retained their identity as long as radiation was released. The result of her work demonstrated for the first time that transmutation from one element to another existed, although in that moment, chemist did not believe in the alterability of the elements. In 1901, Brooks accepted a scholarship at Bryn Mawr, where she completed a doctorate in physics. While there, she received the President's Scholarship to study in Europe. Rutherford wanted Brooks to study with his mentor, Joseph John Thomson, at the Cavendish Laboratory [3,31].

After one year of research in England, Brooks returned to McGill with Rutherford, instead of continuing her studies there. During the period between 1903 and 1904, Brooks made an important observation about radioactivity: when a non-radioactive plate is placed in a radioactive container, the plate becomes radioactive. She related this phenomenon to the volatility of radioactive substances, but Rutherford later found the correct explanation, involving the recoil of the radioactive atom. Moreover, this phenomenon would be used to separate derivates of products of radioactive decay sequences. Otto Hahn and Lise Meitner, four years later, would separate a long-lived isotope of protactinium and investigated it. That year, Brooks published some of her results from Cavendish. In this paper, she indicated an increase and decrease in radioactivity that could only be interpreted in terms of two successive radioactive changes. In

Rutherford's lectures, he talked about the concept of radioactive decay sequences, a presentation in which he referred many times to "Miss H.T. Brooks" [3,15].

In 1904, Brooks accepted a position at Barnard College, a college associated with Columbia University. For the next two years, she taught advanced physics. In 1906, she became engaged to Bergen Davis (1869-1958), a physicist at Columbia University. When Brooks told Laura Gill, the dean of the university, about her marriage, she asked Brooks to resign. In response, Brooks wrote her a letter expressing her anger, as she said she belonged to her profession and her gender, and that she did not believe that a woman should have to leave her profession just because she got married. Finally, Gill answered saying that the College could not afford women for whom their work was secondary. Consequently, Brooks broke the engagement and she resigned from her position [3].

In 1906, she became an independent researcher in the *Curie Institut*. She did not publish any paper on her stay, but it is known that she started a study of the emanation in actinium and continued with the experiments on the recoil of the radioactive atom. Curie invited her to stay during the period of 1907 and 1908, but she applied for a position at the University of Manchester, where Rutherford was to take over the chair of physics. Suddenly, she gave up her research and married Frank Pitcher, who taught her physics at McGill. They married in 1907, in London. The Pitchers went to live in Montreal, where they had three children, two of whom died as teenagers. Brooks never returned to science, probably because of her lack of self-confidence or because of the expectations of Montreal society and her husband's traditional values. Brooks died at the age of fifty-seven from exposure to radioactivity, and specifically, to radium gas. Brooks was only mentioned in papers years after her death. Moreover, there was no record of Brooks' work other than that of the Cavendish Laboratory [15].

5.3.3. Ellen Gleditsch (1879-1968)

Ellen Gleditsch (Figure 5) was born the 29th of December 1879 in Mandal, a small town in southern Norway. She was the first daughter of eleven siblings. Ellen belonged to a middle-class family. Her father, Karl Kristian Gleditsch, was a teacher, and her mother, Petra Birgitte Hansen, was a member of the suffragettes. When Ellen was nine, they moved to Tromsø. Gleditsch graduated from high school in 1895, but in that moment, women were not able to take the exam required to enter to the university.

Figure 5. Ellen Gleditsch (Aune 07/06/22, *via Wikimedia Commons*).

In 1902, she graduated from a non-academic degree in pharmacology and worked as a laboratory assistant. With the support of Eyvind Bødtker, who was her friend and mentor, she struggled to continue her education in Oslo. From her studies, Gleditsch wrote a paper on organic chemistry and sent it to a French newspaper. Her dream was to be able to work with Marie Curie, so Bødtker travelled to Paris to talk with her. Curie finally accepted the proposal, probably because she needed another chemist to do crystallisations [32].

Curie offered Gleditsch to work on the recrystallisation of barium and radium salts. Curie also assigned her a project that was the repetition of experiments performed by British scientists who argued that the exposure of copper salts to radon gas transformed copper into lithium. Finally, Curie and Gleditsch concluded that there was no transformation. During the period of 1908 and 1909, she studied the relationship between uranium and radium content in minerals. This work was in response to Bertram Boltwood (1870-1927) at Yale University and Rutherford at McGill University. They wanted to determine the Ra-U ratio in different ores for then concluding that the amount of radium was proportional to the amount of uranium in ores. She separated the radium from the other components of the minerals and measured the emanation. Gleditsch spent three years working on radium, investigating more than twenty-one different uranium minerals from different parts of the world. Finally, she realised that there were samples with the same ratio and others that not. Her conclusion was that the ratio was not constant, and this created a bit of a buzz, as it meant that uranium was not the mother substance of radium. Today it is known that the Ra-U ratio varies in younger minerals while it is constant in older ones. In the end, Gleditsch became the Curie's personal assistant, staying in Paris for five years (from 1907 to 1912) [33] .

In 1911, she was given a scholarship from the University of Kristiania to give lectures on radioactivity and as a laboratory supervisor, and the next year she completed her *licenciée ès sciences*. In 1913, her mother, her father and one of her brothers died within two months. That same year, she was given a scholarship from the American-Scandinavian Foundation to work in the United States of America. As a result, she wrote to Theodore Lyman (1874-1954) at Harvard University and Bertram Boltwood at Yale University. Lyman refused her request as he wanted to follow the "tradition" of no women in the physics laboratory. Boltwood, like other contemporaries, saw her suggestion as a marriage proposal, not a scientific one. In the end, she went to Yale, where she made her greatest contribution to radioactivity: the precise measurement of the half-life of radium. This was the key number for the study of radioactivity. She reached values of 1642 and 1674 years, which matched the earlier results of Rutherford and Geiger. Currently, the consensus value is 1600 years [33].

After this event, her work gained the respect of American scientists. Lyman offered her a guest position in the laboratory and the president of the American Chemical Society, Theodore William Richards (1868-1928), invited her to see him. To recognise her contributions to the field of radioactivity, the Smith College awarded her an honorary doctorate in 1914. In 1915 and 1916, they published two papers about her results of the half-life of radium. Then, she returned to Oslo in the summer of that year where she was given the opportunity to be an associate professor of radiochemistry in different positions. After the First World War, Gleditsch collected different mineral samples for Richards, who at that time was recognised as the most important analytical chemist, extracted the salts from them and sent them to him. Although he received lead samples from many sources, it was Gleditsch's samples that proved the existence of isotopes, as the atomic masses differed considerably between them [3,33].

She spent the summer of 1917 writing her first book on radioactivity, together with Eva Ramstedt (1879-1974), whom she met while working for Curie. That same year, she was elected to the Academy of Science in Oslo, being the second woman to receive this recognition. She also visited and worked in Paris during the twenties, supervising the laboratory while Curie was in South America. Moreover, Ellen continued her research on isotopes, some of which she did with her sister Liv Gleditsch (1895-1977), who was also a chemist. She wrote a second book on isotopes, which was very successful. In 1919, at the Cavendish Laboratory, Francis William Aston (1877-1945) announced that he had detected two different atomic weights for chlorine, 35 and 37. Later, together with her collaborators, they began to investigate whether chlorine from different sources always had the same isotopic composition. They took chloride from sources other than the marine ones and found that the isotopic composition did not vary from one source to another. In 1929, she was appointed to full professor of chemistry and built up her own research group in the International Federation of University Women [3,32].

In 1932 and 1935, Gleditsch and her assistant repeated the experiments with the Norwegian minerals bröggerite and cleveite, and obtained values of 1691 and 1686 years, respectively.

Between 1930 and 1940, she had the opportunity to make more precise measurements of the radioactivity of rocks using the Geiger-Müller (G-M). She worked with Tibor Gráf, studying the potassium-40 isotope. Together they discovered the presence of much more intense gamma rays than previously reported. They realised that the decaying potassium corresponded to 20% of the total heat produced in the rocks and that the heat emitted by the isotope was about two hundred times that currently produced by all the earth's radioactive elements together [15].

During 1935 and 1937, Gleditsch spent time at the *Institut für Radiumforschung* in Vienna. The 9th of April 1940, in the period of the Second World War, Norway was occupied by German forces. Ellen, Liv, and her brother Adler were arrested for being part of the Resistance. After the war, Gleditsch continued with research and received several awards for her work. At the age of eighty-three, she received an honorary doctorate from *La Sorbonne*, being the first woman to receive this award. She died at the age of eighty-nine, an astonishing age considering that, like Curie, she was heavily exposed to radiation in her early years [32,33].

5.3.4. Lise Meitner (1878-1968)

Lise Meitner (Figure 6) was born the 7th of November 1878 in Vienna. She was the third child of eight siblings. Meitner was the daughter of Philipp Meitner, a lawyer, and Hedwig Skovran, a pianist. Meitner wanted to study physics, so her father paid for a tutor to help her with the university entrance exam. In 1906, Lise Meitner was the second woman to be awarded a physics doctorate at the University of Vienna. She worked for Meyer in the field of radioactivity, studying the absorption of alpha and beta particles in metal foils. Meitner wanted to work in *Curie Institut*, but as Pierre had just died, Curie refused the offer as she was devastated. In 1907, Max Planck (1858-1947), who was not very keen on women scientists, gave her permission to attend his lectures at the University of Berlin. At that time, Otto Hahn arrived in Berlin and was looking for a collaborator, having no objection to work with women. Sadly, the Kaiser Wilhelm Institute for Chemistry refused entry to women. However, the director let Meitner to conduct experiments in the basement [3,34].

Figure 6. Lise Meitner (07/06/22, *via Wikimedia Commons*).

Actinium, with atomic number 89, was the least explored of all the radioactive elements. It was estimated to have a half-life of twenty-five years. The properties of this still unknown element were similar to those of tantalum (atomic number 73) called "eka-tantalum". In 1913, Meitner and Hahn seemed to have found the substance which appeared to be the starting point of the actinium series. They started to work in the Kaiser Wilhelm Institute and Planck provided her with an assistant position. A year later, she became a full member of the Institute. During the First World War, Meitner spent two years, 1915 and 1916, as an X-ray nurse at the Austro-Hungar military hospital and Hahn was recruited to develop toxic gases. After the war, Meitner returned to Berlin to continue with the research, and Hahn occasionally helped her with her project to search for the element that decomposed to give actinium. Meitner's letters to Hahn showed the difficulties in finding the element and explained that the Institute was engaged in war research, being headed by Fritz Haber (1868-1934). Needing large quantities of pitchblende, Meitner asked Friedrich Giesel (1852-1927), an expert radiochemist, to carry out the process. Finally, in 1917, Giesel was able to treat one kilogram of pitchblende and Meitner carried out the last steps of the research. That same year, Meitner was given the position of Head of the Physical section of the Radioactive Unit at the Kaiser Wilhelm Institute for Chemistry. In March 1918, they wrote the publication in which they explained that they had succeeded in finding the new radioactive element. They proposed to call it "protactinium", with the symbol "Pa". Although Meitner did most of the work, Hahn was acknowledged as the author of the initial publication. In contrast, the first paper naming the new element was authored only by Meitner [15,34].

In 1919, Meitner was given the title of full professor at the Kaiser Wilhelm Institute and she underwent "Habilitation" to teach at the university. In 1926, Meitner was the first woman to become a professor of physics in the country. She began to work in new research without Hanh. However, in 1934 Meitner wanted to repeat the experiments performed by Enrico Fermi's group, and asked Otto Hahn to join her. Finally, they worked with the analytical chemist Friedrich (Fritz) Wilhelm Strassmann (1902-1980). By 1937, Meitner and Hahn believed they had identified nine elements, but at the same time, Irène Joliot-Curie claimed to have identified others (section 5.3.7.) [3,34].

When Hitler came to power in 1933, those who were not of Arya ethnicity were dismissed from their academic positions. Meitner was Jewish by birth (later converted to Christianity) and from Austria. When the German army occupied Austria in 1938, the country became part of the German Reich, and she had to escape as her life was endangered. She spent time with the physicist Niels Bohr (1885-1962) in Copenhagen, but then accepted a position in Stockholm at the Nobel Institute for Experimental Physics. While a refugee in Sweden, Hahn wrote to Meitner to tell her that the radium isotope behaved like barium. At the end of 1938, Otto Robert Frisch (1904-1979), who was Meitner's nephew, came to visit her. Both were originally from the University of Vienna, but Meitner was part of the Berlin School of atomic physicists, while Frisch was influenced by Niels Bohr of the Copenhagen School. Frisch was familiar with the theory which considered the nucleus as a liquid drop. This theory treated the uranium nucleus as a drop that was about to split in two parts. The kinetic energy of the fission fragment was 200 MeV. This energy corresponded to the difference in mass between the uranium nucleus and the fission fragments. In their proposal for *Nature*, they pointed out that the so-called "trans-uranium" elements were isotopes of elements already known (i.e., fission products), they identified the ^{239}U as precursor of the element 93, proposed the name "nuclear fission" to talk about the splitting process and concluded that the fission procedure could release large amounts of energy. As Meitner did not have access to good equipment to carry out the experiments, it was Frisch who performed them in Copenhagen. Meitner also sent a copy to Hahn, and he and Strassmann used different methods for the separation. Finally, they quickly identified barium as the product of the neutron irradiation. The 6th of January 1939, Hanh and Strassmann's report was published in *Die Naturwissenschaften*, but with almost no mention of either Meitner or Frisch. A possible reason was that Meitner was a refugee for political reasons, and they not wanted to be involved with her. Despite Meitner and Frisch's theorical interpretation, published the 11th of February, it was the name of Hahn and Strassmann that was linked to the discovery of the fission process. In 1944, Hanh was awarded the Nobel Prize in Chemistry, but the Germans under the Nazi regime forbade German scientists to accept Nobel prizes. Between 1937 and 1965, Meitner was nominated twenty-nine times for the Nobel Prize in Physics and, between 1924 and 1948, nineteen times for the Nobel Prize in Chemistry [15,35].

During the Second World War, Lise stayed in Sweden, refusing to go to the United States of America to build a nuclear weapon in the Manhattan Project. Hahn, despite his anti-Nazi views, stayed in Berlin to work on atomic fission. After the war, Meitner remained in Sweden until 1960 and then moved to Cambridge to be with Frisch. She died before her ninetieth birthday. Lise

Meitner was the first scientist to give experimental proof of nuclear fission, but her role in the discovery has been forgotten for all these years. After the war, not being in danger, Hahn also failed to mention Meitner in his publications. In 1992, the element 109 was named meitnerium, in her honour [3].

5.3.5. Stefanie Horovitz (1887-1940)

Stefanie Horovitz (Figure 7) was born in Warsaw the 17th of April 1887. She was the daughter of the artist Leopold Horovitz. The family moved to Vienna around 1890 and Horovitz enrolled at the University of Vienna in 1907. It is possible that Horovitz and Meitner met when she started university and Meitner left Vienna. In 1914, she graduated receiving a doctorate in organic chemistry for her work on the rearrangement of quinone using sulphuric acid, although in the late 1913, she seemed to have joined the Radium Institute of Vienna to work with Otto Hönigschmid. It was Lise Meitner who suggested him to work with Horovitz. Hönigschmid belonged to the Vienna Institute, but at the same time he was affiliated with the Technical University in Prague. It is possible that Horovitz followed him between both institutions [3,36].

Figure 7. Stefanie Horovitz (07/06/22, *via Wikimedia Commons*).

At the time, Hönigschmid was one of many chemists trying to find out the atomic weight of various elements. Previously, it was claimed that the atomic weight of lead from radioactive sources differed from that of "normal" lead sources. Horovitz's initial task was to separate lead from different residues of radioactive ores from St. Joachimsthal mine, and then to find its atomic weight. The first paper published by Horovitz and Hönigschmid provided a value of 206.736 for the sample from St. Joachimsthal mine and those from a "normal" lead source were 207.190. This difference showed that atomic weights were not necessarily invariant and was the first proof of the isotope concept. Richards repeated this procedure, establishing the existence of isotopes. Consequently, Horovitz and Hönigschmid analysed other samples from different lead sources: bröggerite supplied by Ellen Gleditsch from Norway and pitchblende from German East Africa. The results of these new analyses were even more convincing, as they gave values lower than 206.046. These results showed a difference of more than one unit compared to the samples of St. Joachimsthal mine, and this could not be explained as an experimental error. Horovitz and Hönigschmid made another contribution in the field of isotopes. In 1907, Bertram Boltwood announced the discovery of a new radioactive element, ionium (Io), and it was accepted by the chemists of the time. Between 1914 and 1916, Horovitz and Hönigschmid determined its atomic weight. They showed that it had the same chemical and spectroscopic properties as thorium, but the only difference was the atomic weight. Horovitz also showed that it was an isotope of thorium, thorium-230, and thus provided second evidence for the isotope concept [36].

These papers were Stefanie Horovitz's last publications, after which she disappeared from the scientific record. After the First World War, her interests shifted to the field of psychology, and she started to work as an educational consultant at the Association for Individual Psychology. In 1924, together with the psychologist Alice Friedmann, they built a psychological counselling house for children and teenagers. Horovitz moved to Warsaw after the First World War and the death of her parents, to be with her sister. Allegedly, in 1937 she travelled to her sister's home in Warsaw. After the Warsaw Ghetto was established, the two sisters escaped. However, in order not to endanger the people who took them in, they reported their presence to the Nazi authorities in 1942. Both sisters were sent to the Treblinka extermination camp where they were executed. In addition, Hönigschmid's documents were destroyed during the Second World War [15,36].

5.3.6. Ida Tacke Noddack (1896-1978)

Ida Eva Tacke was born the 25th of February 1896 in Lackhausen, Germany. She was the daughter of Adelberg Tacke, owner of a small varnish factory, and Hedwig Danner. In 1915, Ida completed the *gymnasium* at St. Ursula. Then, she studied at the *Technische Hochschule* in Berlin, graduating with a *Diplom-Ingenieur* in 1919. In relation to her father business, she did a thesis on fatty acid anhydrides of high-molecular-weight. In 1921, she received the doctorate as *Doktor Ingenieur*. Subsequently, she worked in the research laboratory of *Siemens & Halske*. That same year, she met Walter Noddack (1893-1960) at the *Physikalisch-Technische Reichsantalt*, where he was the head of the laboratory [4,28].

After finishing her doctorate, Ida's idea was to pursue the family business. At that time, she was working at the *Allgemeine Elektrizität Gesellschaft* (General Electrical Company) in Berlin, where electrical equipment was produced. But when she met Noddack, she preferred to work with him in the research for the missing elements. At that time, the missing elements from the periodic table before element 92 (uranium) were 43,61,72,75,85 and 87. Dmitri Mendeleev referred to these elements as "eka-manganeses". Tacke and Noddack focused on the two missing elements of group VII, elements 43 and 75, since they were elements close to manganese and would have similar properties. In 1925, Ida was accepted as a guest of the Imperial Physical Technical Institute (PTR) and Walter became the head of the department. The aim of the research was to find the missing elements precisely and to develop analytical methods to isolate them. Ida spent ten months searching for information in textbooks, handbooks and scientific journals. Initially, they followed in the footsteps of Dmitri Mendeleev, who predicted the properties of elements according to their position in the periodic table. Previous research on these elements focused on magnesium minerals, but Tacke and Noddack noticed that the elements of the second and third series of transitions are more often found with other members of these rows than with the first series of transitions. They looked for trace minerals of molybdenum, tungsten, ruthenium and osmium. Furthermore, they asked *Siemens & Halske* for the instrumentation to find the elements, as this company was also interested in this topic. They signed a contract with them and provided with an X-ray spectroscope for the analysis, with the help of Otto Carl Berg (1873-1939), who was an employee of the company. The research was divided into two distinct locations: the chemical part was performed by Tacke and Noddack at the PTR and the X-ray spectroscopic part by Tacke and Berg. Ida learned how to use the X-ray apparatus, with Otto's help, being able to make the measurements herself. In May 1925, the X-ray measurements seemed to identify elements 43 and 75. This discovery was first mentioned in the *Preussische Akademie der Wissenschaften*. Later, the results were published in *the Die Naturwissenschaften*. In both cases, the discovery was described in two parts: a first section, which was called "the chemical part", authored by Walter Noddack and Ida Tacke, and the second section, which was on X-ray spectroscopy, authored by Ida Tacke and Otto Berg. For them, however, it was still necessary to confirm the existence of the two elements by producing weighable samples to be able to carry out research on them. They named the element 43 "masurium" (Ma), in honour of the birthplace of Walter Tacke, and the element 75 "rhenium" (Re), in honour of the river Rhine. In May 1926, Ida and Walter married. They had no children. Then, they decided to find new sources, and between 1926 and 1930, they travelled to Scandinavia and Russia. In 1929, the first gram of rhenium was obtained. From rhenium disulphide, Ida and Walter Noddack suggested the weight of rhenium as 188.71. Otto

Hönigschmid and Rudolf Sachtleben (1856-1917) gave the correct weight value in 1930. After her fame in Germany, she was the first woman to head The Society of German Chemists. Ida was nominated together with Walter for the Nobel Prize in 1933, 1935 and 1937 [15,19].

Between 1930 and 1940, they worked on masurium research, but their results were not reproducible. Element 43 was known to be radioactive and could only occur elusively in nature. Ida concluded that "when heavy nuclei are bombarded by neutrons, it is conceivable that the nucleus breaks up into several large fragments, which would of course be isotopes of known elements but would not be neighbours of the irradiated element". Her opinion was ignored and dismissed, as at that time the theory was another. This proposition would later become known as nuclear fission (section 5.3.4.). Finally, Otto Hahn and Fritz Strassmann identified element 43 as a nuclear fission product of uranium. In 1947, element 43 would be called "technetium" as it would be the first artificially produced element [37,38].

Following these events, Walter became a full professor of chemistry in Freiburg in 1935, and from 1942, the head of the *Institut für Photochemie* in Strasburg. In Strasburg, Ida became professor at the *Deutsche Reichsuniversität*. After the war, Walter was believed to be connected with Nazi belief. Neither Ida nor Walter Noddack were members of NSDAP (political Nazi party), but the university was founded under the German occupation and was a Nazi stronghold. The Noddacks Nazi's believes were another explanation for the names of the new elements. The Rhine and the Masuria were the battle sites where the German army annihilated the Russian forces. These attempts to use chemistry to promote nationalism were unforgivable for many chemists and affected their reputation. Between 1944 and 1956, Ida Noddack was apparently unemployed, and the couple spent some time in Turkey. She died at the age of eighty-two [38,39].

5.3.7. Irène Joliot-Curie (1897-1956)

Irène Curie was born the 12th of September 1897, in Paris. When Irène finished primary school, it was her mother and her colleges who educated her: Marie Curie herself taught physics, Paul Langevin mathematics and Jean Baptiste Perrin (1870-1942) chemistry. Irène's relationship with her mother was built with no affection. Her father died when Irène was only nine years old, and after this event, her mother went through very difficult times (section 5.3.1.). The Curie family had also experienced happy times, but Irène preferred to seek happiness in her studies, especially in the field of mathematics. Before the start of the First World War, Irène went to the *Collège Sévigné* and finished the *baccalauréat* [16,40].

At the outbreak of the First World War, the two Curie sisters were sent with governesses to L'Arcouest, a small fishing village in England where their parents had a cottage. There, Irène was accused of being a German spy, despite her Polish accent. When Irène turned seventeen, they both went to the war front to work as army nurses with the radiology equipment. Those four years were horrible for Irène, but it reinforced her relationship with her mother. At the end of the war, Irène was hired at the *Institut du Radium* as her mother's assistant, while teaching radiology and continuing her studies in mathematics and physics. Her first research consisted in finding the atomic weight of chlorine, looking for variations like those found it with lead. However, her doctoral thesis was on the alpha radiation of polonium. After defending her thesis in 1925, Marie Curie recruited a young, inexperienced researcher, who would be under Irène's tutelage. This young man was Frédéric Joliot (1900-1958). They quickly fell in love and married in 1926, when Irène was twenty-nine. They adopted the family name as Joliot-Curie. Their first daughter, Hélène, was born in 1927. The Joliot-Curie published their first paper together in 1928 [3,41].

In 1932, their first son, Pierre, was born. The Joliot-Curie were interested in the recent findings of Walther Wilhelm Georg Bothe (1891-1957) and Herbert Becker about a new penetrating radiation. First, they studied the radiation that occurred when beryllium was bombarded with alpha particles. That same year, they concluded that boron and beryllium nuclei bombarded with alpha particles had to emit a high energy of gamma rays (photons) to eject protons from substances that contained hydrogen, such as paraffin or cellophane. In addition, James Chadwick, who adapted the experiments conducted by the Joliot-Curie, proposed the existence of a neutron formed in the nuclear reaction between beryllium and alpha particles. Subsequently, Irène and Frédéric, focused their attention to the research for radioelements. They performed experiments in different ways and discovered that if they covered the sources with aluminium or boron foil, it was possible to detect traces of positive electrons, ejected by the neutrons [15,42].

In 1934, when they were studying the bombardment of aluminium with alpha particles, they realised that the emitted positrons were still being produced despite the removal of the alpha particle source. This led them to conclude that a new radioactive element had been formed.

From then on, their task was to isolate the artificially produced element and confirm its existence. Finally, they called this new radioactive element "radiophosphorus" (now known to be phosphorus-30), which has a half-life of three minutes. After that, they started to bomb atoms of boron, aluminium and magnesium with particles. They identified other elements such as silicon-27, aluminium-28 and nitrogen-30. In January 1934, Irène and Frédéric Joliot-Curie discovered "artificial radioactivity" (not existing in nature), which involved the induced artificial radioactivity and the subsequent radioactive decay by positron emission [15].

This artificial synthesis would make the Joliot-Curie family very famous, being awarded with the Nobel Prize in Chemistry in December 1935, in recognition of their synthesis of new radioactive elements. They were offered new positions: Irène began to lead the research group at *La Sorbonne* and Frédéric accepted the position as a nuclear physicist at the *Collège de France*. They continued their work on the production of elements from particle bombardment. In June 1936, Irène Joliot-Curie joined the French government as an Undersecretary of State for Scientific Research under the Popular Front. That same year, Irène was exposed to radiation when a capsule that contained polonium exploded in the laboratory. In 1938, Irène Joliot-Curie and Pavle Savić (1909-1994) decided to follow up a study by Fermi. Both claimed to have identified a trans-uranic element with a half-life of 3.4 hours, which was very similar to lanthanum. It was Meitner, together with his nephew Otto Frisch, who would later explain these observations in terms of nuclear fission (section 5.3.4.). Unfortunately, the fame of the researchers failed because they did not make the correct interpretation [16,41].

Frédéric joined the Resistance at the outbreak of the Second World War. During the war, Irène continued her research work while taking care of her two children. In 1944, the Nazis identified Frédéric as the most important figure in the Resistance, and therefore, the whole Joliot-Curie family was in danger. Irène, Hélène and Pierre, fled to Switzerland. After the war, Frédéric was appointed High Commissioner for Atomic Energy (CEA). Irène, who was a member of CEA, developed the first French atomic reactor in 1948. Their political beliefs, Frédéric being in the French Communist party and Irène being extreme right-wing, continued to cause them many problems. After the retirement of André Debierne, she took up his position as director of the *Institut du Radium* and became a full professor at *La Sorbonne*. Irène would also spend time in Norway with Ellen Gleditsch, her mother's friend. Irène Joliot-Curie died at the age of fifty-nine of leukaemia [3,42].

5.3.8. Marguerite Catherine Perey (1909-1975)

Marguerite Catherine Perey was born the 19th of October 1909 in Villemomble, a suburb of Paris. She was the youngest of five children. Her parents were Émile Louis Perey and Anne Jeanne Perey. Her father died in 1914 when Perey was only five years old. She wanted to study medicine but due to her family's financial difficulties she was unable to do so. Instead, she enrolled at *École Féminine de Enseignement Technique*. In 1929, she graduated with the *Diplôme d'Age de Chimiste* and, as the best women chemist in the school, she was granted an interview with Marie Curie [43].

She was hired at the *Institut du Radium* in Paris and became Marie Curie's laboratory assistant. Her first task was to separate and chemically purify actinium samples and other radioelements from pitchblende. It was a very laborious and time-consuming process, as many fractional crystallisations were needed to isolate a very small amount of this element and separate it from its daughter products. After Marie Curie's death, she was asked to work on finding a precise half-life for actinium-227. This isotope was known to undergo beta emission to give thorium-227, with a half-life of twenty-two years, followed by alpha emission with a half-life of nineteen days. When Perey was making these measurements, she realised that there was a part of the beta radiation that had not been considered. This radiation had a half-life of twenty-two minutes and appeared to correspond with a new element. After several chemical tests, it was concluded that the substance co-precipitated with caesium perchlorate, which meant that it was chemically similar to caesium and that it was an alkali metal. She named this substance as actinium K, symbol "AcK". At that time, the six elements of the alkali metal group did not yet include element 87, which was to be Perey's discovery, the element called "eka-cesium". Perey spent years isolating samples of the new element, a very complicated process as only 1.2% of actinium decomposes into this element. Perey would end up calling the element "francium", after France, her homeland, and with the symbol "Fr". Marguerite Perey was the sole discoverer of the last natural radioelement [15].

On the basis of this great success, Debierne and Joliot-Curie encouraged her to obtain an official scientific degree. She obtained a scholarship from the *Centre National de la Recherche Scientifique* (CNRS) to attend *La Sorbonne*, and in 1946 she received the *Docteur ès Sciences Physiques* with a thesis entitled *L'élément 87: Actinium K*. Perey would later study the other alkali elements and, from 1946 to 1949, held the post of *maître de recherches* at the CNRS. In

1949, she was appointed Chair of Nuclear Chemistry at the *Université Strasburg* and then director of the new associated laboratory. In 1955, the *Université Strasbourg* and the CNRS merged all the laboratories into a *Centre de Recherches Nucléaires*, where Perey became the director of the *Départament de Chimie Nucléaire*. In 1959, Marguerite Perey experienced neuralgia in her hands and head, so she moved to Nice in the hope of getting better. In 1962, she was the first woman to be elected to the *Académie des Sciences*, a post that had hitherto been denied to Marie Curie and Irène Joliot-Curie. Her last award was the *Commandeur dans l'Ordre National du Mérite*, in 1974. Perey was nominated at least five times for the Nobel Prize in Chemistry. She died at the age of sixty-five after suffering from cancer as a result of her research [43].

6. ACTIVITY PROPOSALS FOR THE SUBJECT CHEMICAL DOCUMENTATION

Once an overview has been made to the main discoveries and contributions of women scientists to the periodic table, not only from the scientific point of view but also from the societal difficulties they had to overcome, one of the main objectives of this project is to give voice to all of them. In an attempt to raise awareness and make students reflect on gender inequality and the need for a gender perspective in the field of science, a collection of activities has been created. The example of the *Grau de Química* at the *Universitat de Barcelona* has been used to carry out everything described above, so that the students of the degree are also conscious of the number of women who have contributed to the creation of the periodic table.

The activity proposals have been implemented in *Documentació Química* (Chemical Documentation), a compulsory three-credit (ECT) subject in the fifth semester of the degree. The three learning activities are provided in Appendixes 1, 2 and 3 together with the corresponding teaching guides. The material is written in Catalan as it is the usual learning language in the degree, but it has been designed to be used in any university with a similar curriculum. In this subject, students work on searching for information in different databases. In the case of the following activities, the SciFinder database (Chemical Abstracts search engine) is the one which will be used to solve the proposed questions.

The capacity for analysis and synthesis is mainly valued, as well as the great importance of knowing how to interpret the data provided by the database. In the case of the proposed activities, it is essential that the students know how to search within the publications, normally journal articles or books, for the required information. In addition to these activities being used for students to demonstrate their literature search skills, which is the main specific learning outcome of the subject, they are designed to reach logical conclusions and encourage students to reflect critically on gender-related issues.

6.1. Activity proposals 1 and 2

These two activities target the scientific work developed by Lise Meitner with the purpose of evidencing the strongly biased acknowledgment of the scientific community towards the male scientist.

6.1.1. Activity proposal 1

In activity 1 (Appendix 1), the discovery of protoactinium by Lise Meitner (section 5.3.4.) and Otto Hahn is proposed as the topic of the exercise. In *section a*, the students must find the number of existing publications on protoactinium where Lise Meitner is the author. In *section b* the students must do the same but with Otto Hahn as the author. The purpose of these first two sections is that the students look in detail for how many results Lise Meitner is the sole author of the publications or the main author (meaning the first author), and for how many Otto Hahn is the sole author or the main author of the publications. The students are asked for these results as percentages, because in this way the different results between male and female authorship are more visual for them. In *section c*, the students are expected to comment on the results found above and to reflect on what reasons may exist for the data found. In the last section, students must cite a publication in which Lise Meitner is the author and indicate from what element protactinium is the mother substance.

6.1.2. Activity proposal 2

In activity 2 (Appendix 2), it is explained that Lise Meitner worked together with her nephew Otto Robert Frisch. They concluded that the "trans-uranium" elements were isotopes of already known elements and identified uranium-239 as the precursor of element 93. Lise Meitner, who had previously worked with Otto Hahn (section 6.1.1.), sent him copies of her work. He and Fritz Strassmann searched for separation methods until they found the irradiation product and in 1939, they announced "their discovery" (section 5.3.4.).

In *section a*, students must find the number of existing publications on uranium-239 (in which the topic of uranium fission or irradiation of uranium is discussed) in which Lise Meitner is the author. They also need to find out how many publications she shares with Otto Frisch. In *section b*, students will have to do the same but with Otto Hahn as author. They are also expected to answer how many publications he shares with Fritz Strassmann and whether Meitner appears as the main author in any of the resulting publications. The aim of these first two sections is for students to determine in how many results Lise Meitner is the sole or main author of the publications, how many publications she shares with her nephew, in how many results Otto Hahn is the sole or main author of the publications and how many he shares with Strassmann and Meitner. The students can express this in percentages, in this way the different results between the authorship of Lise Meitner together with Otto Frisch and Otto Hahn together with Fritz Strassmann are more visible to them. In *section c*, the students have to comment on the results found and to reflect on whether this could have happened to other women scientists, both then and now. In the last section, students are asked to cite a publication in which Lise Meitner and Otto Frisch are the authors and detail what products are formed when both uranium and thorium are bombarded with neutrons.

6.1.3. Discussion of *section c* of the proposed activities 1 and 2

By searching first for Meitner as the author of both concepts, we observe that the number of results is always lower than when the search is performed with Hahn as the author of the publications. For activity 1, among the different search results for Lise Meitner, less than half of the results show her as the main author of the publication. Furthermore, there are only 18.75% of results in which she appears as the sole author of the publications. Among the different search results for Otto Hahn, in 27% of the publications he is listed as the sole author. In contrast, a huge difference can be seen when comparing Hahn and Meitner as the main authors of the results found: only 9.09% of the publications by Meitner compared to 81.81% of the publications by Hahn.

For the activity 2, it is observed that among the different search results for Lise Meitner, less than half of the results show her as the main author of the publications (42.86%). In addition, there are only 19% of results in which she appears as the sole author. It is also noted that she has 14.29% of publications with Otto R. Frisch, being a similar percentage compared to the publications where she is the sole author. On the other hand, when the same search is made for Otto Hahn, he is the author of more than twice publications than Lise Meitner (21 results versus 52 results). Out of all the results where Otto Hahn is the author, there are 34.62% of results where he is the only author and 44.23% where he together with Fritz Strassmann are authors (with only four publications that include Meitner). Referring to publications in which Otto Hahn is listed together with Lise Meitner, there is a percentage of 26.92%, of which only in two publications she is listed as the main author.

After analysing the results found in *sections a* and *b*, the students should draw their own conclusions. The aim of *section c* is to awaken the students' capacity for reflection and, through critical thinking, to enable them to analyse the differences between women and men scientists, the discrimination of women in science and particularly, in scientific publications. The publication of a scientific paper confers various benefits on its author, the most important of which are the importance of the publication's impact on the scientific world and the contribution to the author's professional reputation. Therefore, according to the results analysed above, what it is observed is that in both cases, a man takes almost all the credit for the publications made by a woman. In the first case, the work is done by both, but with the awareness that she did most of the work. However, the difference is abysmal when searching for Hahn as the author, especially in reference to multiple authorship (both are listed as authors of the publication), where almost 100% Otto Hahn is listed as the main author. In the second case, Otto Hahn and Fritz Strassmann directly appropriate a work that was not theirs and published before Lise Meitner and Otto Frisch could do so. From then on, there is no turning back as the two of them will remain the main authors of the discovery.

6.2. ACTIVITY PROPOSAL 3

In activity 3 (Appendix 3), it is emphasised that Marie Curie is not the only female scientist who made great discoveries. The exercise aims to get students to look for information about other women who contributed to the periodic table with the objective of showing the imposition of the male figure in women's work environment. In *section a*, different questions are requested about Ida Noddack (section 5.3.6.) and to look for another scientist related to the concept of nuclear fission. From another article, they have to find the name of another female scientist. In *section d*, students must look for information about Marguerite Perey (section 5.3.8.). In all the sections, they are questioned with whom each woman made the discovery for the periodic table. In the last section, students are questioned to reflect on the difference between the women mentioned and the discrimination against women in the world of science.

6.2.1. Discussion of *section e* of the activity proposal 3

The aim of this worksheet is to make students aware that Marguerite Perey's case was exceptional, since most women, especially at the beginning of the twentieth century, worked under the supervision of a man. The other examples presented in the exercise show that Ida (Tacke) Noddack and Irène Joliot-Curie worked with their husbands, and that Lise Meitner worked with a collaborator. The fact that a man worked with a woman in a laboratory was quite normalised, and this was an issue as they usually played a superior role to women. This meant that women were often given a secondary role, especially when it came to mentioning papers in the scientific world. Men were more likely to have a greater impact on scientific publications than women and had "more credibility" when presenting their scientific ideas. Marguerite Perey's solitary discovery of francium was a major turning point, as it had been rare until then. One might think that this encouraged other women to continue their research and to fight for a fair or equal position in the laboratory.

7. CONCLUSIONS

Once the research on women's contribution to the periodic table has been carried out and the different activities have been created in relation to the proposed objectives, the following conclusions can be drawn:

During the time periods considered, all the women, except for Marguerite Perey, worked at some point with a man, whether it was their mentor, husband or laboratory co-worker. In many of the cases, the man exercised a dominant position over the woman in what science concerns, as they were recognised for discoveries that should also have been authored by women or solely by women. Truly, science has been a masculinised and androcentric field and therefore most of these women suffered from the Matilda Effect.

Furthermore, the period in which these women lived affected their lives in a very significant way. There was no gender equality in the field of education until the twentieth century, which means that most of them worked in deplorable conditions, such as unpaid jobs or unsuitable workspaces, they did not have the same opportunities as men, and they often had to leave their hometown behind if they wanted to have a superior education.

In relation to the information available on the topic presented in this project, visibility began to be given at the end of the twentieth century, but especially at the beginning of the twenty-first century. For this reason, the task of science historians, particularly women historians, is essential to give visibility and voice to women who have dedicated themselves to science over the years.

In conclusion, it is necessary to educate students from a gender perspective and to make them aware of the need for gender parity. Therefore, the proposed learning activities will be a great tool for students to develop critical thinking about gender bias and to learn, even if it is only to a small extent, about the contribution of women in science. Including these activities in the university curriculum is the first step towards ensuring that women scientists are present in the actual educational sphere.

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APPENDICES

APPENDIX 1: ACTIVITY PROPOSAL 1

1.1. STATEMENT

Treball bibliogràfic

DOCUMENTACIÓ QUÍMICA, curs 20xx-20xx

UNIVERSITAT DE BARCELONA

Grup: ....

Nom i Cognoms: ....

L'any 1918, la física Lise Meitner i el químic Otto Hahn van escriure una publicació sobre el descobriment d'un nou element radioactiu. Van proposar anomenar aquest element "protoactini".

a) Busca quantes publicacions sobre el descobriment d'aquest element tenen com a autora a Lise Meitner. Comenta els resultats de forma detallada, incidint en la principalitat de l'autoria (fes ús de percentatges per indicar quantes publicacions surt com a autora, autora principal, etc.).
b) Fes el mateix per Otto Hahn. Comenta els resultats incidint en la principalitat d'autoria de Hahn i Meitner (fes ús de percentatges per indicar quantes publicacions surt com a autor, autor principal, etc.).
c) Investigació realitzada per historiadores de la ciència han evidenciat que Meitner va ser la persona que majoritàriament portés a terme tot el procés per arribar al descobriment del protoactini, què opines dels resultats trobats anteriorment? Quines altres raons creus que pot haver-hi per haver trobat aquests resultats? Utilitza els percentatges anteriors per desenvolupar la resposta.
d) De les publicacions on Lise Meitner és l'única autora, busca de quin element el protoactini n'és la substància mare. Cita aquesta publicació.

1.2. TEACHING GUIDE

L'any 1918, la física Lise Meitner i el químic Otto Hahn van escriure una publicació sobre el descobriment d'un nou element radioactiu. Van proposar anomenar aquest element "protoactini".

a) Busca quantes publicacions sobre el descobriment d'aquest element tenen com a autora a Lise Meitner. Comenta els resultats de forma detallada, incidint en la principalitat de l'autoria (fes ús de percentatges per indicar quantes publicacions surt com a autora, autora principal, etc.).

Els estudiants buscaran a la barra de cerca el concepte "Protactinium", i hauran d'afegir a la cerca l'opció de "Author Name" escrivint "Meitner". Sortiran 16 resultats, dels quals tots 16 són de "Meitner, Lise" o "Meitner, L.". De tots els resultats de la cerca, 5 resultats tenen a Meitner com l'autora principal de la publicació, i hi ha 3 publicacions on ella és l'única autora, datades el 1921,1922 i 1928.

b) Fes el mateix per Otto Hahn. Comenta els resultats incidint en la principalitat d'autoria de Hahn i Meitner (fes ús de percentatges per indicar quantes publicacions surt com a autor, autor principal, etc.).

Es fa el mateix procediment però ara escrivint "Protactinium" i després afegint a "Author Name" el cognom "Hahn". Sortiran 25 resultats, dels quals 22 estan escrits per "Hahn, Otto" o "Hahn, O." (es filtren els resultats per aquests 2 noms d'autor). Dels 22 resultats, únicament hi ha 2 on Lise Meitner apareix com l'autora principal. En canvi, en 18 resultats Otto Hahn surt com el principal autor. D'aquests 18 resultats, 6 d'ells tenen com a únic autor a Otto Hahn, datats el 1923, 1925, 1926, 1927, 1932, 1935.

c) Investigació realitzada per historiadores de la ciència han evidenciat que Meitner va ser la persona que majoritàriament portés a terme tot el procés per arribar al descobriment del protoactini, què opines dels resultats trobats anteriorment? Quines altres raons creus que pot haver-hi per haver trobat aquests resultats? Utilitza els percentatges anteriors per desenvolupar la resposta.

Aquesta és una pregunta per fer reflexionar a l'alumnat (opinió personal).

d) De les publicacions on Lise Meitner és l'única autora, busca de quin element el protoactini n'és la substància mare. Cita aquesta publicació.

El protoactini és la substància mare de l'actini. En "l'abstract" de l'article surt com "Act.". Per tal de saber que es tracta de l'actini, podem anar a "Substances" i allà apareix el nom de la substància en qüestió.

Meitner, Lise. Radioactivity and the constitution of atoms. *Festschrift Kaiser Wilhelm Ges. Forderung Wiss. Zehnjährigen Jubilaum* **1921**, 154-161.

APPENDIX 2: ACTIVITY PROPOSAL 2

2.1. STATEMENT

Treball bibliogràfic

DOCUMENTACIÓ QUÍMICA, curs 20xx-20xx

Grup: ....

Nom i Cognoms: ....

UNIVERSITAT DE BARCELONA

A finals de 1938, la física Lise Meitner va rebre la visita del seu nebot Otto Robert Frisch, que era físic. Junts van arribar a la conclusió que els elements que fins aleshores s'havien anomenat "trans-uranis", eren isòtops d'elements ja coneguts. A més, van identificar l'isòtop urani-239 com a precursor de l'element 93 i van donar el nom de "fissió nuclear" al procés de trencament d'un nucli atòmic. Meitner enviava còpies del seu treball a Otto Hahn, un químic amb qui havia treballat prèviament, i juntament amb Fritz Strassmann, que era químic, van buscar mètodes de separació fins a identificar el producte d'irradiació de neutrons. L'any 1939, Hahn i Strassmann van atorgar-se el descobriment de tots aquests successos.

a) Busca el nombre de publicacions que tenen com a autora del descobriment de l'isòtop urani-239 (parlant sobre la fissió o la irradiació de l'urani) a Lise Meitner. Comparteix alguna publicació amb Otto Frisch? (fes ús de percentatges per indicar quantes publicacions surt com a autora, autora principal, quantes publicacions comparteix amb Otto Frisch, etc.).
b) Fes el mateix per Otto Hahn. Comparteix alguna publicació amb Fritz Strassmann? Apareix Meitner com autora principal en alguna publicació? (fes ús de percentatges per indicar quantes publicacions surt com a autor, autor principal, comparteix amb Meitner o Strassmann, etc.).

c) Quina és la teva opinió sobre els resultats trobats anteriorment? Creu que el que li va succeir a Lise Meitner li ha passat a altres dones científiques? Creus que aquest fet continua succeint? Utilitza els percentatges anteriors per desenvolupar la resposta.

d) Entre les publicacions de Lise Meitner juntament amb Otto Frisch, busca quins dos productes es formen quan l'urani és bombardejat per neutrons. I quins es formen quan el tori és bombardejat per neutrons? Cita l'article on es troba aquesta informació.

2.2. Teaching guide

A finals de 1938, la física Lise Meitner va rebre la visita del seu nebot Otto Robert Frisch, que era físic. Junts van arribar a la conclusió que els elements que fins aleshores s'havien anomenat "trans-uranis", eren isòtops d'elements ja coneguts. A més, van identificar l'isòtop urani-239 com a precursor de l'element 93 i van donar el nom de "fissió nuclear" al procés de trencament d'un nucli atòmic. Meitner enviava còpies del seu treball a Otto Hahn, un químic amb qui havia treballat prèviament, i juntament amb Fritz Strassmann, que era químic, van buscar mètodes de separació fins a identificar el producte d'irradiació de neutrons. A l'any 1939, Hahn i Strassmann van atorgar-se el descobriment de tots aquests successos.

a) Busca el nombre de publicacions que tenen com a autora del descobriment de l'isòtop urani-239 (que parlin sobre la fissió o la irradiació de l'urani) a Lise Meitner. Comparteix alguna publicació amb Otto Frisch? (fes ús de percentatges per indicar quantes publicacions surt com a autora, autora principal, quantes publicacions comparteix amb Otto Frisch, etc.).

Els estudiants hauran de buscar a la barra de cerca el concepte "uranium-239" i afegir "Meitner" a "Author Name". D'aquesta cerca s'obtenen 21 resultats dels quals tots ells contenen a "Meitner, Lise" o "Meitner, L." com a autora. De les 21 publicacions, 9 tenen a Meitner com autora principal, i només en 4 d'aquestes apareix com a única autora. Comparteix 3 publicacions amb Otto Frisch.

b) Fes el mateix per Otto Hahn. Comparteix alguna publicació amb Fritz Strassmann? Apareix Meitner com autora en alguna publicació? (fes ús de percentatges per indicar quantes publicacions surt com a autor, autor principal, comparteix amb Meitner o Strassmann, etc.).

Es repeteix el procés anterior però posant a "Author Name" el cognom "Hahn". Amb la primera cerca tenim 133 resultats, dels quals 52 són de "Hahn, Otto", "Hahn, O." o "HANH,O". D'aquests 52 resultats, 18 són publicacions on ell és l'únic autor.

Dels 52 resultats obtinguts, hi ha 23 publicacions on els autors són Hahn i Strassman, de les quals només quatre inclouen a Meitner. En canvi, hi ha 14 publicacions de Hahn i Meitner, de les quals només n'hi ha dues on ella surt com l'autora principal: una publicació on tots 3 apareixen com a autors (1937) i una altra on únicament apareixen Hahn i Meitner (1936). Totes dues publicacions es van fer abans de la publicació de 1939 on Hahn i Strassmann van atorgar-se els mèrits.

c) Quina és la teva opinió sobre els resultats trobats anteriorment? Creus que el que li va succeir a Lise Meitner li ha passat a altres dones científiques? Creus que aquest fet continua succeint? Utilitza els percentatges anteriors per desenvolupar la resposta.

Aquesta és una pregunta per fer reflexionar a l'alumnat (opinió personal). S'espera que els i les estudiants parlin de les diferències en el nombre de publicacions obtingudes en a) i b) a més de mencionar que la figura de Meitner queda en un segon pla.

d) Entre les publicacions de Lise Meitner juntament amb Otto Frisch, busca quins dos productes es formen quan l'urani és bombardejat amb neutrons. I quins es formen quan el tori és bombardejat per neutrons? Cita l'article on es troba aquesta informació.

Es repeteix la cerca que s'ha fet al primer apartat i es troba l'article en qüestió.

En bombardejar l'urani es formen isòtops de bari i de criptó. Quan es bombardeja el tori es formen isòtops de bari i de lantani.

Meitner, Lise; Frisch, Otto R. Disintegration of uranium by neutrons: a new type of nuclear reaction. *Nature* **1939**, 143, 239-240.

APPENDIX 3: ACTIVITY PROPOSAL 3

3.1. STATEMENT

Treball bibliogràfic

DOCUMENTACIÓ QUÍMICA, curs 20xx-20xx

UNIVERSITAT DE BARCELONA

Grup: ....

Nom i Cognoms: ....

Marie Curie és la dona científica amb més renom. És coneguda a escala mundial pel descobriment dels elements radi i poloni, i pel seu innovador estudi sobre la radioactivitat. Malauradament, Curie representa un cas aïllat, i és que es tracta d'una excepció dins la ciència, ja que al llarg de la història s'ha ignorat el paper de moltes dones que han contribuït en la creació de la taula periòdica. El treball d'aquestes dones ha quedat en l'oblit o eclipsat, de manera injusta, pel treball d'un home.

Una de les dones científiques més importants en la creació de la taula periòdica fou Ida Noddack. A partir d'un article publicat l'any 2017, respon les preguntes següents:

a) Quins elements va descobrir Ida Noddack? Juntament amb qui va fer-ho? Quina relació tenia Noddack amb el codescobridor? Quin concepte va ser proposat per ella abans que ningú altre? Quina altra dona està relacionada amb aquest concepte? Cita l'article on has trobat la informació.

Centra't en la científica mencionada, a més de l'Ida Noddack, en l'article i fes una nova cerca d'un article del 2012 que la menciona. Respon:

b) Quin element va descobrir aquesta dona? Juntament amb qui va fer-ho? Des de quin any col·laboraven junts?

c) Troba el nom d'una altra dona científica (no mencionada fins ara) dins del mateix article. Què va descobrir l'any 1934? Juntament amb qui va fer-ho? Quina relació tenien? Cita l'article on has trobat la informació.

Una altra dona que va contribuir a la creació de la taula periòdica fou Marguerite Perey.

d) Quin element va descobrir? Juntament amb qui va fer-ho? En quina institució va ser pionera? Busca la informació en un article que parli explícitament sobre el sistema periòdic.
e) Quina diferència trobes entre les dones mencionades en els diferents apartats anteriors? Reflexiona sobre la discriminació de la dona en el món científic, una pràctica molt habitual fins al segle XX i encara present en l'actualitat.

3.2. TEACHING GUIDE

Marie Curie és la dona científica amb més renom. És coneguda a escala mundial pel descobriment dels elements radi i poloni, i pel seu "innovador" estudi sobre la radioactivitat. Malauradament, Marie Curie representa un cas aïllat, i és que es tracta d'una excepció dins la ciència, ja que al llarg de la història s'ha ignorat el paper de moltes dones que han contribuït en la creació de la taula periòdica. El treball d'aquestes dones ha quedat en l'oblit o eclipsat, de manera injusta, pel treball d'un home.

Una de les dones científiques més importants en la creació de la taula periòdica fou Ida Noddack. A partir d'un article publicat a l'any 2017, respon les preguntes següents:

a) Quins elements va descobrir Ida Noddack? Juntament amb qui va fer-ho? Quina relació tenia Noddack amb el codescobridor? Quin concepte va ser proposat per ella abans que ningú altre? Quina altra dona està relacionada amb aquest concepte? Cita l'article on has trobat la informació.

Els estudiants hauran de buscar a la barra de cerca "Ida Noddack". Apareixeran 22 resultats, però en acotar la cerca l'any 2017 a "Publication Year" es reduiran a 3. D'aquests, només quedarà un article que respongui les preguntes enunciades (a partir de "l'abstract").

Ida Noddack va descobrir dos elements: el reni i el "masuri" (actualment conegut com a tecneci). Aquest descobriment el va fer juntament amb Walter Noddack, el seu marit. Ida Noddack fou la primera a suggerir el concepte de fissió nuclear, però no va ser acceptat pel món científic. L'altra dona relacionada amb aquest concepte va ser Lise Meitner (el nom es pot buscar a partir del cognom Meitner que surt a "l'abstract" de l'article).

Marshall, James; Orna, Mary Virginia. Ida Noddack-Tacke: The actual proposer of nuclear fission before Hahn. *American Chemical Society* **2017**, 20-24.

Seguint amb la dona de l'última pregunta i a partir d'un article del 2012, respon:

b) Quin element va descobrir aquesta dona? Juntament amb qui va fer-ho? Des de quin any col·laboraven junts?

Els estudiants hauran de buscar a la barra de cerca "Meitner" (358 resultats) i després reduir els resultats obtinguts a "Publication Year" cercant 2012. Només apareixen 3 resultats dels quals 1 és el precís.

Lise Meitner va descobrir l'element 91, el protoactini. Aquest descobriment el va fer juntament amb Otto Hahn. Col·laboraven junts des de 1907.

c) Troba el nom d'una altra dona científica (no mencionada fins ara) dins del mateix article. Què va descobrir l'any 1934? Juntament amb qui va fer-ho? Quina relació tenien? Cita l'article on has trobat la informació.

Seguint amb el mateix article, l'altra dona científica (que no sigui ni Lise Meitner ni Ida Noddack) és Irène Joliot-Curie. Irène Joliot-Curie va descobrir la radioactivitat artificial juntament amb el seu marit, Frédéric Joliot-Curie.

Kant, H. Lise Meitner and the (supposed) Transuranic Elements. *Annalen der Physik* **2012**, *524*, 6-7.

Una altra dona que va contribuir a la creació de la taula periòdica fou Marguerite Perey.

d) Quin element va descobrir? Juntament amb qui va fer-ho? Marguerite va convertir-se en la primera dona en què? Busca la informació en un article que parli explícitament sobre el sistema periòdic.

Els estudiants buscaran a la barra de cerca el nom "Marguerite Perey". Sortiran 15 resultats dels quals, per buscar el que parla explícitament sobre el sistema periòdic, hauran d'afegir l'opció de "Periodic System" a l'apartat "Concept".

Marguerite Perey va descobrir el franci. No ho va fer juntament amb ningú sinó que el va descobrir ella sola. Va ser la primera dona en ser escollida membre de la Académie des Sciences (French Academy of Science).

Orna, Mary Virginia. My favourite element. Francium: uranium's daughter, Perey's Discovery. *Journal of chemical education* **2009**, *86*, 1364.

e) Quina diferència trobes entre les dones mencionades en els diferents apartats anteriors? Reflexiona sobre la discriminació de la dona en el món científic, una pràctica molt habitual fins al segle XX i encara present en l'actualitat.

(Pregunta de reflexió personal.)