

Miguel A. Catalán's CXXV Anniversary

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Abstract

We would like to memorialize the CXXV anniversary of the following physicist: Miguel A. Catalán (1894-1957), who contributed to science advancement and to define the atomic model of matter, and quantum theory, hundred years ago. The objective of the research was to define the biography of Miguel A. Catalán and his contribution to the advancement of science. To this end, this work has been historically documented.

Keywords

Miguel A. Catalán, Atomic Physics, Atomic Spectroscopy, Spectrum of Manganese, Atomic Model

1. Introduction

We would like to remember the 125th birth anniversary of the physicist Miguel A. Catalán (1894-1957), who, one hundred years ago, contributed to the advancement of science and the definition of the atomic model of matter.

He was a great teacher and pedagogue as well; he was my professor.

Even before becoming a doctor, on February 6 of 1917, he had applied for a fellowship in order to study abroad. In order to further his studies in the United States, he was planning on undertaking his postgraduate studies the following year. The Board assessed his English, and on October 27 he was granted a fellowship for a year stay in America. Due to the World War, he wasn't authorized to leave the country, as he belonged to a reserve that could be called upon at any moment, hence losing the effect of the fellowship granted (Barceló, 2009).

Fellow at the Imperial College

However, still longing to pursue postdoctoral studies, specializing in chemical spectrographic analysis, he received a fellowship to study in London, at the Imperial College (1919-1921), exactly one hundred years ago to date. Miguel worked during that course as a research student at the Imperial College of London under Alfred Fowler's instruction, an astrophysics professor. At that time, on the basis of the newly formulated theory of Niels Bohr on the origin of spectra, atomic spectroscopy represented one of the key spots in physics research. Bohr brought forth a correlation between the spectrum of the element and the energy level of its electrons in orbit around the nucleus (Barceló, 2012).

In the laboratories of Alfred Fowler (1868-1940) at Imperial College, Catalán studied the spectrum of manganese, discovered patterns (See Figure 1), took photographs and deduced a repetitive law of the spectrum of that element, which allowed to finish deciphering the spectrum of that element, and therefore, defining a new reference standard for manganese and the creation of a new method of spectrographic research. The new method was that of multiplets, a new tool to interpret the spectra of complex elements. He also made a logical deduction in his research, which turned out to be a breakthrough in understanding the structure of matter, and in the interpretation of atomic cortex based on the concept of chemical valence.

His multiple discoveries caused admiration which swiftly spread. Before writing his own report on his research in the journal *Nature*, on July 28 of 1921, his name is referenced in English for the first time, in an article written by the Indian scientist Megnad Saha, Catalán's co-researcher in the laboratory of the Imperial College of London (Barceló, 2012).



The young researcher Miguel A. Catalán (See Figure 2) immediately became

Figure 1. The spectrum of manganese and its representation including multiplets in the report published by Catalán: "Series and other regularities in the spectrum of manganese", in Philosophical Transactions of the Royal Society of London as a summary of his work (1922).



Figure 2. Miguel A. Catalán in the Physics laboratory, observing the image of a spectrum.

an investigator of reference throughout the international scientific community, long before his work had been published.

Meanwhile, his report on the results obtained was received by the Royal Society on February 22, 1922. Fowler himself read them out during the session on March 23. In July of that year the results appeared in the famous Philosophical Transactions of the Royal Society of London, under the title *Series and other regularities in the spectrum of manganese*. Subsequently, on the occasion of the opening of the Congress, held by the British Science Association in 1926 for the progress of Science, Fowler's inaugural address was dedicated to Catalán's research with honorary mention in recognition of his work (Memoria JAE 1924-1926).

2. Atomic Models

In the modern age it was John Dalton (1766-1844) who proposed the first scientifically supported atomic model in 1803. His model allowed advocating that chemical substances react in fixed stoichiometric proportions (the law of constant proportions).

In the aftermath, Gilbert Newton Lewis (1875-1946) proposed the cubic atomic model (1902), in which electrons are arranged according to the vertices of a cube, in furtherance to the valence-bond theory in chemical bonds.

Joseph John Thomson, (1856-1940) identified electrons as particles in 1897, and discovered isotopes, as well as inventing the mass spectrometer. He conceived a new atomic model in 1904, the so-called "pudding model", in which electrons are immersed in the positive "mass" of the atom.

However, Ernest Rutherford (1871-1937) was the first to take into account the nucleus as the center with a cloud of electrons surrounding it, in so doing, pro-

posing a new atomic model (1911) approaching that of reality.

Antonius van den Broek (1870-1926), within the same year, put forward the idea that the atomic number or the total number of protons in each atom of that element corresponded to the charge of its atomic nucleus. Upon the basis of that proposal, Henry Moseley (1887-1915) contributed to the development of this model, quantitatively upholding the concept of the atomic number.

The existence of electron layers in the atom was confirmed through experiment by Charles Barkla (1877-1944), through the development and perfecting of the X-ray spectroscopy in those years. Barkla was awarded with the Nobel Prize in Physics in 1917.

In 1913 Niels Henrik David Bohr (1885-1962) proposed a similar and even more complex model, in which electrons orbited in circular trajectory around the atomic nucleus. The number of electrons in each orbit increases from inside outwards. In addition, he assured that by the electron changing its orbital, for example from an outer orbit to an inner orbit, a photon is either being emitted from discrete energy or being absorbed, if the trajectory was the opposite. The model therefore sustained that of quantum mechanics.

This model also allowed for proof of other spectroscopic phenomena, for example, the one in which Balmer mathematically deduced the ongoing relationships between multiple hydrogen emission lines, and even laid the groundwork for imagining the structure of simple atoms, such as those of Hydrogen (See **Figure 3**).

Relativistic Generalization of the Atomic Model of Bohr

Given certain inconsistencies of the previous model, back in 1916, Arnold Sommerfeld (1868-1951) suggested a relativistic generalization of Bohr's atomic model and the quantification of the angular momentum to be as follows:

1) Electron shells are distributed in orbits around the nucleus. The orbital eccentricity was determined by the azimuthal quantum number.

2) From the second energy level, energy sub-levels are likely to exist.

This initial model was subsequently extended because of the results drawn from the aforementioned research conducted by Miguel A. Catalán in the laboratory of Alfred Fowler, London.



Figure 3. Hydrogen atom illustration in the book by Miguel A. Catalán and Andrés León "Physics and Chemistry", the seventh grade, edition dated 1945.

This is the way we shape a model in which electrons can pass from one atomic orbital to another, either by emitting or absorbing a quantum of energy in the form of a photon. This transition from one orbital to another with different energies advocated the spectroscopic phenomena of emission and absorption of electromagnetic radiation by atoms. This is what set the conceptual development of quantum mechanics in motion.

Afterwards, the atomic model was developed by Heisenberg (1925), putting forth the mathematical formulation based on both frequencies and amplitudes of the absorbed radiation and that emitted by the atom and its energy levels. Or the atomic model set forth by Schrödinger (1926) in which electrons are considered waves of matter. However, the model of the *preceding quantum theory*, initially based on Niels Bohr's proposal, still held up as the most accepted, and used for its simplicity. The aforementioned theory went through its development in between 1900 and 1925, prior to modern quantum mechanics, and has roots in the recently referenced models.

3. Catalán's Contributions

Catalán terminated his stay in the laboratory of the Imperial College of London and returned to his previous work as a researcher. In those days, Arnold Johannes Wilhelm Sommerfeld visited Madrid; along with Bohr, and obtained a leading position in the field of theoretical Atomic Physics.

Previous to the publication of the works of Catalán, Arnold Johannes Wilhelm Sommerfeld was aware of the results therein obtained, and was hence eager to meet Catalán in person. In that first interview, Miguel didn't think twice about handing over a copy of his work on manganese, even before it had been published (Barceló, 2012)!

The reaction of the German was immediate and that very night he reviewed the paper, contacting Catalán the very next day to express his great interest in the research (Pérez-Piñar López). This is what Catalán narrated during the PhD course:

Sommerfeld had formulated his theory on internal quanta lacking much data, with alkaline and alkaline earth metals, to then come across from one day to the next, a great deal of data which I provided, to back up his theory. He called me the next day and that conversation was to be the beginning of a grand friendship lasting to date (Catalán, 1946).

In August of that same year, Sommerfeld submitted a new text on the interpretation of spectra of complex elements: *Annalen der Physik* in accordance with the research of Catalán. In the document he repeatedly acknowledges the work of Herr Catalán, paying tribute to him as a driving stimulus in carrying out this extension (Aguilar Peris, 2000). And he adds: "Herr Catalán's multiplets in the matter of arc and spark spectra of Mn and Cr are perfectly in tune with the theoretical scheme of internal quantum numbers and are the best experimental basis that this theory needed" (Aguilar Peris, 2000). Even though Sommerfel already had experimental data to confirm his theoretical intuition, the data was not consistent enough, nor completely suitable. After meeting with Catalán, he provided the experimental information required to consolidate the model of atomic structure. With the documentation provided by Catalán, he had all the necessary tools to back up his theory regarding internal quantum numbers.

Sommerfeld appraised Catalán's discovery and showed that the observed lines of the spectrum, originating in transitions between multiple electronic states, arise from the diversity of quantum states that those atoms can acquire. They deduced that the spectrum lines corresponded to variations in the energy state of the electron hailing from a change in its orbit. This discovery was even more crucial than that initially put forward by Niels Bohr, as it opened for detailed studies and explanations of the structure of atoms in a more complex way than that of hydrogen (Barceló, 2009).

Sommerfeld became a new popularizer of the young Catalán's discoveries (See **Figure 4**) after that meeting. Four of the most important scientists of those times: Fowler, Bohr, Russell and Sommerfeld, recognized his contributions and spread word throughout the world of his discoveries and his new method of multiplets (Barceló, 2012)!

4. Other Testimonials

That same year, in June (1922), Bohr, the great scientific figure, commented on the results obtained by Catalán in his lectures on Theory of Atomic Structure held in Göttingen, in front of students of the great Heisemberg and Pauli ... (Bohr, 1995)

In the first Solvay Conference held after the World War I, Niels Bohr himself defined Catalán as a scientific prescriber. He spoke of the consequences that should be expected resulting from the research of Catalán on the high frequency spectra (Menéndez-Pidal, 2004).



Figure 4. A. Einstein visits the laboratories in Madrid, Catalán is wearing a laboratory gown, the fourth from the right.

Miguel A. Catalán accepted that the spectrum of a pure element was formed by the representation of electron excitations in diverse atom shells, and hence those regularities in the spectrum, which he called Multipletes. He identified the first triplet that assigns the two electrons of chemical valence and the first electron of the next shell.

Thus it defines a physical correlation for each element between the structure of the atom and the Multipletes observed in its spectrum, allowing for the identification of spectrum multiplets for each element which led to the deduction of the structure of that atom and the confirmation of the number of electrons and protons of that element. This discovery granted a breakthrough regarding the structure of matter and in physics in general.

Along with his discoveries, Catalán provided the experimental proof needed for theoretical physicists such as Sommerfeld and Bohr, which led to the definition of the atomic model structure.

- He set a new procedure for interpreting the spectra of complex elements.
- *He confirmed the physical causality of the supposed correlation of each element and its spectrum, in relating the regularities discovered in the spectrum with positions of the electrons in the atom.*

This contribution was the most highly valued of those made by Catalán to science, concretely to spectrography and atomic physics, however, it was not the only one (Velasco, 1977).

On these grounds, we may cite Stern and Guerlach (1921), Paschen-Back (1921), Landé (1923) and Catalán (1922) as core representatives of experimentation within that period (Campos, 2000).

The contribution made by Catalán towards the development of the atomic model and quantum theory has been reiterated in other texts:

Precisely, one of the board members of the Laboratory of Physics Investigation, Miguel Antonio Catalán (1894-1957), to whom the greatest contribution made in Spanish history towards Physics is acknowledged with the discovery of "multiplets" in 1921, that meant an important step in the development of quantum theory, adequately proving the quantum number that Arnold Sommerfeld had introduced in 1920 (Centro Español de Metrología, 2007).

Consequently, Catalán deduced how the spectrum should be interpreted according to the order observed. Knowing how to measure the frequency and energy level in accordance to each spectrum line, and from there determine the levels of electron energy in orbit and jumps made, identified with those spectral lines observed. He achieved a scientific discovery that identifies the cortical structure of the atom, as well as the energy levels of those cortical electrons, which consequently, determine new magnitudes that can be measured. It led to determining successive relationships between those magnitudes, contributing to the model of atomic structure allowing us to define the constitution of matter (See Figure 5).

Catalán followed the transcendent compass that stands for finding an order in



Figure 5. Illustration of the report based on Catalán's research. Catalán's text: "Series and other regularities in the spectrum of manganese" read by Fowler at the session held on 23 of March and published in Philosophical Transactions of the Royal Society of London.

the seemingly complex and arbitrary arrangement of the lines of an atomic spectrum. This finding was axiomatic to the successive comprehension of the role of angular moments of cortical electrons, for the overall development of quantum theory of the previously mentioned magnitudes, and for its application to many other problems (Barceló, 2009).

When Catalán identified certain lines of the manganese spectrum with those of electrons of valence, he was deciding on the origin of this phenomenon, its natural causes, and defining a correlation of the spectrum and the structure of atom.

He is providing proof of the correlation between energy level shifts of electrons and the spectrum. That is why its discovery is spreading so quickly. In my modest opinion, because of his deduction, based on valence electrons, he nailed it and opened a new path capable of testing the existing theories about the structure of matter.

With Catalán's discoveries, and possibly because of his impressive deduction, there is something incredibly compelling about what can only be described as the confirmation of the true model of the atom. He ceased being just a chemical spectroscopic analyst and became a forerunner in researching atomic structure. In a nutshell, he also reshaped spectroscopy as an experimental physics discipline, as well as the method of chemical analysis. From that moment on, physicists would fundamentally use spectroscopy to puzzle out the true nature of the atom (Barceló, 2012).

As Velasco recalls (Velasco, 1977), the incorporation of the concept of spinning into science must be appreciated as a result of Catalán's discovery on multiplets. The authors themselves, Uhlenbeck and Gondsmidt, gave him credit in their work published in 1925 for the following: "The simplicity of the atom spectra consists of an electron that rotates around the central part that contains only complete groups of electrons, and these groups are magnetically inert. When we move to more complicated atoms, in which several electrons rotate around such a center, we discover new phenomena, since we have to take into account other influences on the axis of rotation of each electron, in addition to the pair, due to its movement in the electronic field of the core."

This is a turning point in the explanation of why complex multiplets appear and the comprehension of the "branching" of the spectra that usually occurs by adding a new electron to an atom, and for which, until this point, we had lacked a satisfactory explanation.

In fact, it seems that the introduction of the concept of the spinning electron makes it easier to get the picture of the successive construction of atoms, described by Bohr in his general discourse on the relationship between spectra and the natural system of chemical elements. Furthermore, it might be of assistance to explain significant results obtained by Pauli, when in need to resort to a contrived mechanical "duality" in bonding the electrons in the atom (Uhlenbeck, & Goudsmit, 1925).

Professor Velasco wrote: "The most outstanding point for us lays in Uhlenbeck's and Gondsmidt's statements about how, above all, they highlight the application of their discovery to the explanation of the multiplets discovered by Catalán. We shall emphasize the importance of the spin concept in other aspects of the atomic structure theory."

By the hand of the multiplets, the electron spin discovery elegantly cleared up all the doubts that remained dormant in Sommerfeld's theory (Velasco, 1977).

Goudsmit himself reconfirms Catalán's contribution in his subsequent article: M.A. Catalán discovered the existence of higher multiplicity soon after. Sommerfeld matched the Catalán results with the vector model (Goudsmit, 1927).

The best analysis on multiplets and Catalán's work can be seen, for example, in the groundworks of Velasco (1958, 1977), Shenstone (1958), Hund (1974, especially, p. 114 and at seq.), Kenat and De Vorkin (1990: p. 179-180), Jammer (1989: p. 125) and Mehra and Rechenberg (1982)."

5. Multiplets Method

Catalán elaborated a new spectrographic research procedure to determine the structure of matter. Internationally, laboratories began to apply the methodology, and concluded that this was the best cutting-edge research method in physics at the time. It became quite clear that this was a moment of revolutionary upsurge in the field, with the structure of matter in the limelight.

Sommerfeld was especially grateful for the kindness that the young Spanish researcher had shown towards him, hence showing a keen interest in his future, and wanting him to go to the Rockefeller Foundation in pursuit of continuing his research in Germany.

In 1924, thanks to Sommerfeld, Catalán obtained a fellowship from the International Education Board of the United States, through the JAE, in the wake of working at the University of Munich in 1924-1925. Sommerfeld became aware of Catalán's potential and expressed his desire to be immediately informed on any new findings (Barceló, 2012).

By the end of that stay, Sommerfield did not want to lose his close relationship with Catalán, so he requested a new fellowship in the Foundation for his deputy Bechert to accompany Catalán in Madrid. From then on, Catalán maintained a close relationship with the school of theoretical spectroscopy in Munich. In fact, *between* 1925 *and* 1926 *he published six collaborative papers, in German and in Spanish.*

In the fellowship application file, the head of the European area of the IEB, Trowbridge, recommends the grant to Bechet as follows: "I anticipate that Catalán shall become the center of a school of researchers in this field ... (Barceló, 2009). The IEB institution itself, which had granted the stay pension in Germany, at Sommerfeld's request, after a rigorous follow-up to the scholarship, confirmed the great potential of the Spanish researcher as well (Barceló, 2012).

6. Rockefeller Foundation

Yet, the interest shown by the Rockefeller Foundation in Catalán continued. His working conditions in Spain were not so up to date, so the International Education Board of the Foundation started fundraising. On April 25, 1925 Cabrera and Moles met in Madrid with Trowbridge. It enabled the start of a project designed to build a new research center in accordance with the needs of Catalán so that he could continue his research from Spain.

However, the idea to undertake this project continued, so Charles E. Mendenhall visited Madrid in March 1926 with interest in supporting Catalán's research on behalf of the IEB. His analysis was quite critical, the project nonetheless went ahead. Catalán, following the given recommendations, requested additional equipment and instrument supply. What is more, he sought advice from other researchers among foreign universities, with preference for the American ones. An ambitious project has been launched, consisting of creating a new research center designed by Miguel Catalán from the very beginning (Barceló, 2012).

The new building and its facilities, sponsored by the Rockefeller Foundation, opened in 1933. However, the civil war began in Spain a few years later, which prevented Catalán from continuing with his research. Foreign scientists, Americans in particular, such as Russell, Meggers, Charlotte Moore, George Harrison and Allen G. Shenstone, showed concern for his situation and offered for him to continue working in the USA, but the Spanish government forbid this opportunity.

At the end of the war, owing simply to his political ideology, Catalán was sanctioned and had many proceedings against him that even hindered his access to the laboratory and interrupted his research as well as him being able to teach at the university. The scientific texts written by Catalán were banned from being published, even those related to his previous research. He was not allowed to interact with any researchers from other countries for over fourteen years.

He conducted several research stays in the US afterwards; he was invited by the MIT, the NBS and Princeton University, and delivered various lectures there. He was young when he passed away in 1957. After his death, very few acts were summoned in his memory, but publications continued referencing his works. The last work in coresearching with Meggers and Olga García-Riquelme was entitled: "The first spectrum of manganese, Mn I". It was edited by the Journal of Research of the National Bureau of Standards in 1964.

No tributes were made to him until the International Astrophysical Union held a congress in August 1970 in Sydney and they decided to give a group of craters on the moon his name, Catalán. From that moment on, we began to recuperate his memory, acknowledging the importance of our teacher (Barceló, 2009). In his centenary year, we once again remember him (See Figure 6).

Back in 1972, for the fiftieth anniversary of the discovery of multiplets, his colleagues in Spain honored his memory. The event was organized by his friend, disciple and colleague Rafael Velasco.

Among the numerous participants we would like to point out the renowned Charlotte Moore Sitterly, from the Naval Research Laboratory of the U.S. N.B.S. and the U.S. Washington D. C., who gave a talk on multiplets in astrophysics. W. C. Martín of the U.S. N.B.S.; Jacquinot of the C.N.R.S. French; Garton from the Imperial College of London; Spector from the School of Theoretical Spectroscopy of Israel; Bengt Edlen from the University of Lund, Sweden; Klinkenberg from Holland; Crooker from Canada; Shenstone from Princeton University, the N. J. U.S.A, one of his best friends and foreign coworkers, who gave an endearing talk entitled "Multiplets" and R. Velasco, his disciple, great admirer, scientist and publicist of his work, ... (Barceló, 2012).

7. Conclusions: Atomic Model B-S-C

We would not like to consign to oblivion Miguel A. Catalán's genuine contribution to spectrography nor his research on asymmetries of the Zeeman effect (see **Figure 7**). There is a need to mention his contribution to raising our awareness of the structure of matter.

As we have already mentioned, Sommerfeld himself spread the news and eased our professor's discoveries.



Figure 6. The postcard and the seal of the Spanish Postal Service, issued in 1994, commemorating the centenary of the birth of Miguel A. Catalán.



Figure 7. Miguel A. Catalán with Pieter Zeeman (Photo by Gonzalo Menéndez-Pidal).

The Committee for the Promotion of Studies and Scientific Research registered the following in the record book dated 1924-26: "Upon Professor Sommerfelden's appointment as a member of the Royal Society of London, during the conference, he mentioned the Catalán 'multiplets' as a reason for the rapid development of spectrography in recent years" (Memoria JAE 1924-1926).

It should not come as a surprise that those contributions made by Catalán should be acknowledged in terms of scientific knowledge on the structure of matter, on the atomic model, even if we express our highest recognition one century later.

Therefore, I would like to propose:

... that the atomic model of Bohr-Sommerfeld be remembered as the **Atomic model of Bohr-Sommerfeld-Catalán**, given the personal contribution of Miguel A. Catalán to these conclusions, recognized by the other two researchers.

To that end, the relativistic generalization of the atomic model formulated by Bohr and carried out by Sommerfeld, leading to a new and more coherent and elaborate atomic model, should be remembered as coming from the results obtained by Catalán's spectroscopic studies (Barceló, 2019).

We wish to insist on recognizing the contribution made by the research of Miguel A. Catalán, coinciding with the CXXV anniversary of his birth.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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