EPJ manuscript No.
(will be inserted by the editor)

The blossoming of quantum mechanics in Italy: the roots, the context and the first spreading in Italian universities (1900-1947)

Adele La Rana[1 2 3,a] and Paolo Rossi[4 5,b]

[1] Department of Physics and Astronomy - University of California Riverside, CA 92507 (USA)
[2] Department of Physics of Sapienza University of Rome - Piazzale Aldo Moro 5, 00185 Rome (Italy)
[3] INFN Section of Sapienza University of Rome - Piazzale Aldo Moro 5, 00185 Rome (Italy)
[4] Department of Physics - University of Pisa, Largo Bruno Pontecorvo 3, 56127 Pisa (Italy)
[5] Centro Fermi, Museo Storico della Fisica e Centro Studi e Ricerche "Enrico Fermi" - Rome, Italy - Piazza del Viminale 1, 00184 Rome (Italy)

Abstract. The widespread positivist approach of physics research in Italy at the turn of the XIX and XX centuries did not provide a fertile ground for the scientific debate on the atomic structure of matter, which instead raged beyond the Alps in those same years and which gave birth, during the 1920s, to the quantum revolution. Experimental investigations in spectroscopy and radioactivity were carried out with discrete success in the 1910s and early 1920s by Italian physicists such as Antonino Lo Surdo and Rita Brunetti in Florence, stimulating an empirical knowledge of early quantum theory and the acquisition of the related laboratory skills. However, the theoretical framework necessary for the reception and development of the postulates and formalisms of quantum mechanics started to be cultivated in Italy with a delay of a few decades compared to Central European countries. The diffusion of quantum studies - with their unprecedented drive toward an integration of experiment and theory - took hold in Italy beginning from the establishment of the first theoretical physics chairs (1926) at the Universities of Rome, Florence and Milan, whose origins are here described in detail. Furthermore, the present paper presents a systematic analysis of the appearance of the quantum mechanical concepts in Italian university courses between 1927 and 1947.

1 The limited reception of quantum theory in Italy until 1925

The introduction among Italian physicists of the concepts of early quantum theory (linked to the names of Max Planck, Albert Einstein and Niels Bohr) was greatly slowed down by some structural and cultural factors.

[a] e-mail: alarana@ucr.edu ; Adele.LaRana@roma1.infn.it
[b] e-mail: paolo.rossi@unipi.it

First, physics as an academic discipline was greatly underpowered compared to the European countries most advanced in the field, i. e. England, Germany and France. The institutional status of Italian physics in the second half of the XIX century - and still for a few subsequent decades - was very weak, especially when comparing the growth rate of the Italian physicist's community and the equipment and funding available to them with those of other countries[1].

Besides the chairs of experimental physics (whose number never exceeded 18 units between the end of the 19th century and 1920, rising to 21 after 1925), there were only a dozen chairs of *mathematical physics*. The latter dealt with issues which were intrinsically different from those investigated by the research field that already in the 1870s German scholars called *theoretical physics*. Mathematical physics developed mathematical tools for physics and focused on the properties of the equations used to describe phenomena, rather than on the properties of phenomena themselves. Instead, the theoretical physicist, according to Ludwig Boltzmann's words, "*has the task of finding - as we used to say - the fundamental causes of the phenomena or - as we prefer to say today - it has the task of joining the experimental results that we have obtained under unified points of view*" [Boltzmann 1905, p. 94]. In the second half of the nineteenth century, theoretical physics was already a research field of its own in Mitteleuropean countries, and, although quite different from theoretical physics as meant in the 1920s, it had already acquired its academic identity. *Theoretische Physik* chairs were present in German universities since the last decades of XIX century [Leone, Robotti 2006]. and special Institutes for Theoretical Physics were established in Berlin, Göttingen, Munich and Vienna, under the directorship of scientists such as Max Planck (1858-1947), Hendrik Lorentz (1853-1928), Woldemar Voigt (1850-1919), Ludwig Boltzmann (1844-1906), Paul Drude (1863-1906). Each of these physicists contributed at a different level to creating the conditions for the birth of the new physics in the early 20th century.

In Italy, the first series of lectures officially called "theoretical physics" was a *course on assignment* (*corso su incarico*) held at the University of Naples by Antonio Carrelli (1900-1980), in the academic year 1925-26 [La Rana, Rossi 2019]. No information about its contents is available, but presumably it dealt with thermodynamics and special relativity. Notoriously, the first chair of theoretical physics was established only in 1926 and the phrase "theoretical physics" had come into use in the Italian scientific community only a few years earlier: there was a half-century delay, compared to Germany and Austria.

The situation was much different in Italy, not only for the lack of financial and organizational means, which resulted in poorly equipped laboratories and inadequate training to address the new research frontiers which animated the scientific debate beyond the Alps. Indeed, we must consider also some peculiar cultural factors, originated by the radically empiricist orientation of contemporary Italian physicists, for whom mathematics had only the function of "putting order" in the data. Within this methodological framework, the physical laws could be obtained only from the analysis of the data and not through a hypothetical-deductive process based on the formulation (and subsequent empirical verification) of theoretical models. As a result, there was no discussion of atomism in Italy, at least until the First World War, nor participation in the international debate that was then opposing *energetics* and *atomism* [Dragoni 1989; Maiocchi 1991; Giuliani, Marazzini 1994; Brush 1968]. The first Italian theoretical study on the kinetic theory of gas dates back to 1916 and is due to Carlo Del Lungo [Del Lungo 1916]. In the pre-war period, Einstein's theory of Brownian motion was not yet recognized, and the few articles on black body did not

[1] On the general lines of the practice of physics in Italy between mid-19th and early 20th century, and the related institutional developments, see [Dragoni 1989; Reeves 1980].

mention Planck's theory, as in the case of Virgilio Polara [Polara 1910], or criticized it, as in the case of Luigi Puccianti [Puccianti 1912] and Raffaele Augusto Occhialini [Occhialini 1913].
The first Italian physicists who understood the importance of mathematics in the formulation of effective physical models in the context of atomic physics were Antonio Garbasso (1871-1933) and Orso Mario Corbino (1876-1937). Garbasso was the first to consider the connection between atomic models and spectroscopy [Garbasso 1904, 1905, 1909]. Already in 1908 [Corbino 1908], and then in a couple of popular articles [Corbino 1909a, 1912], Corbino described the hypothesis of quantization of energy, without however showing particular enthusiasm for what was perceived as a sort of "accounting artifice" (a point of view shared, morever, by Planck himself).
The topic of energy quantization found some space only after the discovery of the Stark-Lo Surdo effect, the shifting and splitting of spectral lines of atoms and molecules due to the presence of an external electric field. In the same issue (January 1914) of *Il Nuovo Cimento* in which Antonino Lo Surdo (1880-1949) announced the discovery of the new phenomenon [Lo Surdo 1914a, 1914b, 1914c], Garbasso published a note in which he related the effect to the quantization of hydrogen levels proposed by Bohr one year before [Garbasso 1914]. Garbasso's main objective seemed to be enhancing the role of Antonino Lo Surdo in the debate on the priority of discovery, rather than supporting Bohr's theory. The proof is that, although in his analysis of the phenomenon observed by Lo Surdo he had preceded also the Danish pioneer of the atomic model, Garbasso did not return to investigate these fertile issues later, preferring to deal with classical physics.
Even in the immediate post-war period, little attention was paid to the results obtained until then in the context of the first quantum theory, except for its implications in the field of spectroscopy (Rita Brunetti) and in the chemical theory of valence (Giacomo Luigi Ciamician, Maurizio Padoa, Adolfo Campetti). Particularly significant was the role of Rita Brunetti (1890-1942). She had graduated in Pisa in 1913 on spectroscopy topics, under the guidance of Angelo Battelli (1862-1916). In 1915, she became assistant of Garbasso (who in turn had collaborated with Battelli), continuing to engage in spectroscopy research. From 1918, she started to interpret experimental results in the light of quantum theory; in 1921, she wrote a review article on the atomic nucleus, expressing great appreciation for Bohr's theory [Brunetti 1921]. However, it was a purely instrumental adherence, devoid of any attention to the strictly theoretical implications raised by the quantization. Paradoxically, this attitude favored a sort of passive acceptance of quantum theory, which instead did not occurr in the case of Einsteinian relativity, towards which philosophical prejudices on the nature of space and time generated for a long time a wall of hostility also by greatly authoritative physicists, such as Quirino Majorana (1871-1957). In this same spirit, when after 1925 the *new* quantum theory - *quantum mechanics*, according to the name coined by Max Born in 1924 [Born 1924] - asserted itself, it was easier for some to accept Werner Heisenberg's matrix approach rather than Erwin Schrödinger's wave mechanics, based on the concept of wave function and thus perceived as too theoretical and speculative. Indeed, Heisenberg showed that at the atomic or microphysical level the only measurable variables were the frequency and intensity of electromagnetic radiation absorbed or emitted by electrons within atoms. From this point of view, mechanical variables, as long as they are not directly measurable and cannot be objects of experimentation, must be redefined in terms of such measurable variables. As a consequence, stated by Heisenberg himself in 1927, a fundamental indeterminacy affects mechanical variables. Heisenberg's operational approach was more naturally acceptable for the experimentalists than Schrödinger's wave theory.

2 Quantum mechanics (1925) and the first Italian competition for a chair of theoretical physics

The first diffusion of Heisenberg and Schrödinger's quantum mechanics and the creation of the first chairs of theoretical physics in Italy are largely parallel processes, linked to the names of the same scientists. Therefore, it is worth treating these issues in a unitary way, focusing on the physicists who won the first competition and immediately became the bearers of the new ideas in the world of Italian physics: we mean Enrico Fermi (1901-1954), Enrico Persico (1900-1969) and Aldo Pontremoli (1896-1928), whose curriculum up to the early thirties we will later briefly retrace. Indeed, the spread of quantum mechanics was closely related to the appearance on the scene of a new generation of young physicists (many of them in their thirties), who were open to the new physical ideas developed especially in Germany. Without forgetting the already mentioned (and significant) exceptions of Corbino and Garbasso, Italian professors already in service before 1926 did not participate with their scientific research activities in the conceptual revolution going on in those years. In order to introduce the first Italian theoretical physics competition (1926), we need to take a small step back to 1925, when the University of Cagliari launched a competition for a professorship in mathematical physics [Graffi 2010]. The commission was composed by:

- Giovanni Guglielmo (1853-1935), experimental physicist, Dean of the Faculty of Cagliari;
- Tullio Levi-Civita (1873-1941), full professor of rational mechanics in Rome;
- Roberto Marcolongo (1862-1943), full professor of rational mechanics in Naples;
- Carlo Somigliana (1860-1955), full professor of mathematical physics in Turin;
- Vito Volterra (1860-1940), full professor of mathematical physics in Rome.

It is impossible to conceive an academically more authoritative commission for that epoch. The candidates were Sante Luigi Da Rios (1881-1965), Enrico Fermi (1901-1954), Giovanni Giorgi (1871-1950), Mario Pascal (1896-1949), Enrico Persico (1900-1969), Francesco Sbrana (1891- 1959), Rocco Serini (1886-1964) and Angelo Tonolo (1885-1962). The average age of the commissioners (over 60) classified them as members of the 'old' generation of physicists, who, taken as a whole, had experienced with relevant cultural difficulty the birth of the new and revolutionary theories appeared in the first decades of the twentieth century. In turn, the average age of the competitors (over 36) made the twenty-five year old Fermi and Persico stand as true outsiders. With the exceptions of Giorgi (graduate in civil engineering) and Fermi and Persico (graduates in physics), all other candidates were graduates in mathematics. However, it is worth noting that, at the time, Fermi was in charge of rational mechanics and mathematical physics in Florence and from January 1925 he had obtained the *libera docenza* (literally *free lectureship*, a license to teach at the University) in mathematical physics, while Persico was Volterra's assistant for the chair of mathematical physics in Rome.

One should remind that, while the *ternate* (the three winners of a public competition for an academic professorship) often had a chance of recruitment elsewhere, in the present case only the first winner would get a chair, since there were no other open professorships of mathematical physics in Italy. The commission unanimously recognized that two candidates, Fermi and Giorgi, were definitely superior to all others and therefore the winner had to be one of them. As for the third place, the commissioners unitedly established that it had to be disputed between Persico and the best of the group of "mathematicians", among whom, however, Serini stood out.

There was a clear rift in the commission, when it came to identifying the prevailing criterion by which first place was to be awarded. In the end, Giorgi prevailed

with three votes, while the votes in favor of Fermi were two, of which one certainly came from Levi-Civita and the other most likely from Volterra. Therefore, the support of the only experimental physicist present in the commission, the Dean Giovanni Guglielmo, was presumably decisive. The third place went unanimously to Serini. The outcome of the 1925 competition disrupted the plans of Orso Mario Corbino, who was director of the Royal Physical Institute in via Panisperna in Rome since 1918, and who almost certainly, in the event of a victory by Fermi, would then try to have him transferred to Sapienza University as soon as possible. In his view, ensuring the presence of Fermi in Rome was the key to turning the Physical Institute of Sapienza in a leading research institution in the international scientific panorama. Given the circumstances that occurred in Cagliari, Corbino did not dare to promote the call for a professorship in mathematical physics at Sapienza University, taking into account the evidently plausible risk that also in this case Fermi would not be first in ranking. At that point, he must have had the idea of promoting the creation in Rome of the first Italian chair of theoretical physics.

According to what Edoardo Amaldi wrote, Corbino's operation succeeded due to the foresight of the great mathematicians Guido Castelnuovo, Tullio Levi-Civita and Federigo Enriques, who supported the establishment of the new discipline and of the related chair[2]. However, Amaldi fails to mention another influential mathematician of great prestige, whose support certainly had a relevant weight: Vito Volterra [Battimelli 2013]. The four mathematicians were professionally interested in the new theoretical developments of physics and were aware that the theoretical physics would have had a hard time finding its own space in the context of mathematical physics. Nevertheless, it was not a trivial decision to solicit the creation of a chair that brought the new discipline out of the mathematical sphere to which, up to that moment, its issues had belonged in the Italian academic tradition. Such a policy certainly did not fail to provoke negative reactions in the academic world, as Carlo Somigliana underlined several years later in an important essay on Italian mathematical physics [Somigliana 1939; Polvani 1939].

The commission met in Rome at the end of 1926, on November 1, November 8 (two sessions, morning and afternoon) and November 9, and had the following composition[3] [Gariboldi 2020]:

- Michele Cantone (1857-1932), full professor of experimental physics in Pavia from 1898, then in Naples from 1904;
- Orso Mario Corbino (1876-1937), full professor of experimental physics in Messina from 1905, then in Rome from 1908;
- Antonio Garbasso (1871-1933), full professor of experimental physics in Genoa from 1903, then in Florence from 1913;

[2] In Amaldi's words (Edoardo Amaldi Archive, Physics Department, Sapienza University of Rome, Section *Amaldi Eredi*, Box 19, folder 2): "Fermi's call from the Faculty of Mathematical, Physical and Natural Sciences was prepared and carried out successfully by Corbino who was the only one who could follow and appreciate the new developments in modern physics. However, he had the support of various mathematical colleagues, in particular Guido Castelnuovo (1865-1952), Federigo Enriques (1871-1946) and Tullio Levi-Civita (1973-1941). Although possessing more distant scientific competence, they were aware of the exceptional qualities of the young theoretical physicist who, among other things, had already published lasting contributions also concerning the theory of General Relativity, which they were well able to appreciate." The original quotation is in Italian, here translated by the authors.

[3] The primary source of information about the first Italian public competition for a chair of theoretical physics is constituted by the minutes of the competition sessions: Central State Archive (Rome), MPI DGIS DIV 1, Concorsi cattedre universitarie 1924-1954: *Commissione per il Concorso di Fisica Teorica nella R. Università di Roma. Verbali delle Sedute.*

- Gian Antonio Maggi (1856-1937), full professor of infinitesimal analysis in Messina from 1886, then of rational mechanics in Pisa from 1895 and finally of mathematical physics in Milan from 1924;
- Quirino Majorana (1871-1957), full professor of experimental physics at the Turin Polytechnic since 1914, then in Bologna since 1922.

We are again in presence of the most authoritative national exponents of their discipline (in this case experimental physics). The average age was around 60, but at least the three youngest scholars (Q. Majorana, Garbasso and Corbino) had also carried out research activities that fell consistently within the lines of development of contemporary physics. There were only four competitors: Carlo del Lungo (1867-1950), Aldo Pontremoli (1896-1928), Enrico Persico and Enrico Fermi. It is immediately worth noting that in this case the real outsider was Del Lungo, not only fifty years old (while the others were aged between 25 and 30), but also scientifically far from the most recent problems of theoretical physics, having written only a series of articles on *Il Nuovo Cimento* on the kinetic theory of gases. In fact, the commission soon came to the unanimous conclusion that Del Lungo did not qualify for the purposes of the competition. All the other candidates had some connection with Corbino, who had been the advisor of Persico and Pontremoli. In the first meeting, the commission appointed Garbasso as President and Corbino as rapporteur. In the second session the commission examined the titles of Fermi and Persico and established unanimously that[4] [Gariboldi 2020]

> Fermi highly deserves to get the chair of Theoretical Physics, and [the commissioners] believe that they can found on him their best hopes for the affirmation and future development of theoretical physics in Italy. [...]
> He is today the most prepared and most worthy to represent our country in this field, where such a high and feverish scientific activity is being carried out in the world.

The commission, however, also reserved a positive opinion for Persico, noting that

> Persico reveals with his scientific activity a perfect possession of the mathematical instrument, a singular clarity of mind, penetrating ingenuity and a valuable aptitude for setting and solving the problems under study, with balanced proportion between the means employed and the extent and character of the results to be achieved.

In the third session, the commission examined the titles of Pontremoli, and the judgment was that

> Pontremoli demonstrates with his titles wide and varied culture, also in the fields of modern theoretical physics, excellent mathematical preparation, lively talent, fervent imagination and great passion for scientific research.

Voting followed for the formulation of the ranking. With the first vote the commissioners agreed that all three candidates were included. There was then unanimity in considering Fermi in first place, while a disagreement emerged on the order in which to place Persico and Pontremoli; hence Garbasso proposed to proceed by voting. Fermi ranked first with a unanimous vote, while for the second place three votes went to Persico and two to Pontremoli, who then obtained unanimously the third place. In the fourth session, Corbino read the report written by Garbasso, and then the commission approved the report and sent it to the Ministry of Education.

[4] Central State Archive (Rome), MPI DGIS DIV 1, Concorsi cattedre universitarie 1924-1954: *Commissione per il Concorso di Fisica Teorica nella R. Università di Roma. Verbali delle Sedute.*

3 The winners of the competition for the first Italian professorship in theoretical physics

3.1 Enrico Fermi

Fermi was born in Rome on September 29, 1901. He was admitted to the Scuola Normale Superiore in 1918 and graduated in physics at the University of Pisa on July 4, 1922 (his supervisor was Luigi Puccianti) [La Rana, Rossi 2020] [Segrè 1996]. Strongly interested in the theoretical aspects of physics, even before graduating he studied as a self-taught Bohr's and Sommerfeld's quantum theory and Einstein's general relativity and provided significant contributions in both fields, including the correction of discrepancies in the theory of electromagnetic masses and the introduction of the so-called "Fermi coordinates". After graduating, he met Corbino, who immediately recognized the extraordinary talent of the young researcher. Fermi then obtained a scholarship abroad, which allowed him to spend a (not particularly fruitful) period with Max Born in Göttingen in 1923 and a more pleasant one with Paul Ehrenfest in Leiden in 1924. In a series of papers published in *Il Nuovo Cimento* between 1923 and 1924 he presented various results relating to the Bohr-Sommerfeld quantum theory, and in particular the *Considerations on the quantization of systems which contain identical elements* [Fermi 1924].
Back in Italy, he taught mathematics for chemists for one year (1923/24) in Rome, and then from 1924 to 1926 he was in charge for the course of rational mechanics and mathematical physics in Florence. In those years, he quickly mastered the basics of the new quantum theory and came to formulate the statistics of identical particles subject to an exclusion principle (Fermi-Dirac statistics, 1926).
In 1926, at the end of the competition, he was immediately recruited by the Physics Institute of Rome, where he settled in the autumn of the same year. In the meantime, he had published, again in *Il Nuovo Cimento*, the papers *On the theory of collision between electric atoms and corpuscles* [Fermi 1925] and *Arguments for and against the hypothesis of light quanta* [Fermi 1926a], still located in the context of Einstein's and Bohr's theories. Even the treatise *Introduction to atomic physics* [Fermi 1928] deals mainly with the old theories, and only about thirty final pages concern quantum mechanics, but without any discussion on its foundations. It is singular that Fermi's first paper on the new quantum theory, which was published in the early months of 1926 almost in coincidence with the appearance of Schrödinger's work [Schrödinger 1926], was written in German for the review *Zeitschrift für Physik* with the title *The wave mechanics of the impact process* [Fermi 1926b], and did not have an Italian version. In the immediately following years, Fermi produced some significant contributions to the new theory, including the article *A statistical method for the determination of some properties of the atom* [Fermi 1927] and the work *On quantum electrodynamics* [Fermi 1929], fundamental for the development of quantum field theory. Even in the essay *Interpretation of the principle of causality in quantum mechanics* [Fermi 1930], Fermi assumed a strictly pragmatic attitude that was not attentive to the conceptual and philosophical foundations of the theory. In 1933, he formulated the theory of beta decay, but then immediately went on to deal with nuclear physics, obtaining the extraordinary experimental results that earned him the Nobel Prize.

3.2 Enrico Persico

Persico was born in Rome on August 9, 1900 and was a friend of Fermi since their adolescence. He studied physics at Sapienza University and graduated on November 22, 1921, having Corbino as a supervisor [Battimelli 2015]. In 1921/22 he was assistant

at the Observatory in Rome, then from 1922 to 1927 he was assistant of Corbino, with some teaching assignments in minor courses. Ranked second in the competition for the first Italian chair of theoretical physics, in 1926, he immediately took service at the University of Florence where he held the theoretical physics course from 1926/27 to 1929/30.
Far more interested than Fermi in the conceptual implications of the new quantum mechanics, and certainly influenced, at least indirectly, by the ideas supported at the time by neo-positivist thinkers, Persico soon intervened on the foundations of the theory. On this issue he published in *Il Nuovo Cimento* two reviews: *Wave mechanics* [Persico 1927] and *Recent viewpoints on the foundations of physics* [Persico 1928], and the article *On the relation $E = h\nu$ in wave mechanics* [Persico 1930], while in that period he gave no significant contributions to the applications of the theory.
In 1930 Persico moved to the chair of theoretical physics at the University of Turin, where he remained until 1950, before moving back to Rome.

3.3 Aldo Pontremoli

Pontremoli was born in Milan on January 19, 1896. After the first two years at the Polytechnic of Milan he moved to Rome, where he graduated in physics in 1920. He was assistant at the Physics Institute of Rome from 1921 to 1924, and afterwards was in charge of the course of complementary physics (and director in charge of the corresponding institute) in Milan from 1924 to 1929. He was the third winner of the 1926 competition, but his call on the chair of theoretical physics in Milan met academic obstacles. The theoretical physics course was however entrusted to him for the academic year 1927/28, but at the beginning of 1928 he decided to take part in the polar expedition of Umberto Nobile and perished in the Barents Sea on May 25, 1928 sharing the tragic fate that befell the enterprise [Gariboldi 2015].
He had no chance of making original contributions to modern quantum mechanics. Nevertheless, the list of his publications (which appeared almost exclusively in the Proceedings of the Royal Academy of Lincei) shows that Pontremoli had had attention for the new theories from their birth and carefully followed their developments, as also emerges from his article *On Rutherford's neutron* [Pontremoli 1923] and from the booklets of his lectures [Gariboldi 2020].

4 The second and third competitions for a chair in theoretical physics in Italy

It should be noted that acceptance of the existence of the new academic discipline was certainly neither immediate nor generalized. This is proved by the fact that ten years passed before a second theoretical physics competition was launched, in 1937. The commission was composed as follows[5]:

- Enrico Fermi (1901-1954) (president), full professor of theoretical physics in Rome (1927);
- Antonio Carrelli (1900-1980) (secretary), full professor of experimental physics in Naples (1932);
- Orazio Lazzarino (1880-1963), full professor of mathematical physics in Pisa (1925);
- Enrico Persico (1900-1969), full professor of theoretical physics in Turin (1930);

[5] Central State Archive (Rome), MPI DGIS DIV 1, Concorsi cattedre universitarie 1924-1954.

– Giovanni Polvani (1892-1970), full professor of experimental physics in Milan (1929).

One may appreciate the presence of the two surviving theorists, joined by a mathematical physicist and by two experimentalists in charge of theoretical physics courses (Antonio Carrelli and Giovanni Polvani, as we shall see later). The 1937 competition was preceded by the attribution to Ettore Majorana (1906-1938?) of a chair for "alta fama di singolar perizia" ("high reputation for singular expertise"), destined to Naples, and it was won by Giovanni Gentile jr (1906-1942), Giulio Racah (1909-1965) and Gian Carlo Wick (1909-1992), later called respectively in the seats of Milan, Pisa and Palermo. The third competition for a theoretical physics chair was held almost ten years later. The 1946 commission was composed by[6]:

– Enrico Persico (1900-1969), full professor of theoretical physics in Turin since 1930;
– Edoardo Amaldi (1908-1989), full professor of experimental physics in Rome since 1937;
– Gilberto Bernardini (1906-1995), full professor of experimental physics in Bologna from 1938, and from 1946 in Rome;
– Antonio Rostagni (1903-1988), full professor of experimental physics in Padua since 1938;
– Rocco Serini (1886-1964), full professor of mathematical Physics in Pavia from 1927.

Again we observe an unavoidable prevalence of experimentalists, albeit strongly interested in the theoretical aspects of physics, because the first two generations of theorists was for various reasons almost exhausted. Pontremoli had died in 1928, as we mentioned, during the polar expedition lead by Umberto Nobile aboard the airship *Italia*. Fermi had emigrated to the USA in December 1938. At the end of March 1938, few weeks after the beginning of his course at Naples University, Ettore Majorana had mysteriously disappeared. Giovannino Gentile had died prematurely in March 1942, from septicemia resulting from complications of a dental abscess. Racah had emigrated to Jerusalem after the promulgation of the anti-semitic laws in Italy, in 1938. Wick had left Italy for the USA in 1945. Therefore, at the time of the third competition, only Persico remained of the first two generations of theoretical physicists.
Finally, the third-generation full professors of theoretical physics were Nicolò Dalla Porta (1910-2003), Bruno Ferretti (1913-2010) and Piero Caldirola (1914-1984), who were respectively called to the seats of Padua, Milan and Pavia in 1947 [La Rana, Rossi 2019, 2020].

5 The diffusion of quantum mechanics in the main academic seats until the Second World War

The penetration of new ideas into the major Italian universities was not simultaneous. In the sites where there was neither a professorship nor a theoretical physics assignment, the teaching of wave mechanics and Heisenberg's mechanics was often entrusted to the courses of higher physics or mathematical physics. It is therefore worth examining the individual situations separately, highlighting those in which, at the research level or even only at the educational level, there is evidence of an effective assimilation of the new concepts. It should be noted that elements of the so-called

[6] Central State Archive (Rome), MPI DGIS DIV 1, Concorsi cattedre universitarie 1924-1954.

old quantum theory - quantization according to Bohr-Sommerfeld, quantization of electromagnetic radiation and black body theory - had already become part of the experimental courses in various Italian universities, in some cases already shortly after the end of the World War I. It was, of course, a phenomenological and experimental approach, in line with the widespread attitude in the community of Italian physicists. With the gradual emergence of quantum mechanics, in the second half of the 1920s, and the establishment of the first chairs of theoretical physics, the concepts of quantum mechanics slowly began to make their way into lessons alongside the early quantum theory. We now report in chronological order the universities where theoretical physics courses for university students were gradually activated, covering the period until 1947, when a new generation of theorists took charge of the academic training in the field[7].

5.1 Naples

The University of Naples was the first Italian academic center in which a course explicitly titled "Theoretical physics" took place. It was a course on assignment (*corso su incarico*), i. e. a course without a dedicated chair, which was assigned year by year to a *professor in charge* (*professore su incarico*), who could be a full professor, an assistant or a simple expert on the subject qualified to teach (qualification of *libera docenza*, i.e. *free lectureship*). The professor in charge for the course of theoretical physics in Naples was Antonio Carrelli (1900-1980), who held lessons from the year 1925, when he was assistant at the Institute of Physics in Naples, until 1950, with two interruptions in the 1930s. The first interruption was between 1931 and 1932, when he first moved to Catania as full professor of Experimental Physics, and then to Utrecht, for a period of study. The second interruption was in the academic year 1937-38, when the chair of theoretical physics was established at Naples University and assigned to Ettore Majorana.
After Majorana's disappearance in March 1938, Carrelli resumed his theoretical lectures in parallel with the experimental physics course. It is worth noticing that, since 1925 and during the 1930s, the theoretical physics course in Naples was biennial and was dedicated to third- and fourth-year students of the four-year course for the degree in physics[8]. We do not have indications that Carrelli held quantum physics lessons within his course in the 1920s, because unfortunately no notes or lesson records relating to that period can be found, but we can follow the evolution of his interests thanks to his publications[9].

[7] The following data concerning the first courses and chairs of theoretical physics in the Italian Universities have been obtained analyzing several primary sources in different archives. The main general references were consulted at the Central State Archive and at the Biblioteca Casanatense, in Rome: 1) Annuari del Ministero della Pubblica istruzione, Roma, Tip . Elzeveriana, 1894-1929; 2) Annuari del Ministero dell'Educazione nazionale, Roma, Provveditorato generale dello Stato, 1930-1943; 3) Annuari del Ministero della Pubblica istruzione, Roma Istituto poligrafico dello Stato, 1944-1951.

[8] Instead, theoretical physics was not compulsory for the last two years of the undergraduate course in mathematics.

[9] Publications by A. Carrelli in *Il Nuovo Cimento* in the 1920s: *La decomposizione elettrica delle righe spettrali*, 25 (1923) 213-229; *Sulla ruota di Barlow*, 1 (1924) 369-385; *Sul valore delle energie caratteristiche dei livelli X*, 3 (1926) 144-151; *Sulle righe semiottiche*, 3 (1926) 247-253; *Sul teorema della concordanza delle fasi di De Broglie*, 4 (1927) 137-141; *Sul fenomeno di Compton*, 4 (1927) 142-145; *Sulle nuove statistiche*, 4 (1927) 282-288; *Sul calcolo dell'energia di dissociazione delle molecole biatomiche*, 5 (1928) 9-13; *Sulle relazioni intercedenti fra le varie statistiche e la meccanica ondulatoria*, 5 (1928) 73-76; *Sull'enunciato*

A work that well represents his attention to new developments in quantum theory at the turn of the 1920s is *Quantum theory. Critical exposition of the new physics*, published in 1931 in the Memoirs of the Pontifical Academy of Sciences [Carrelli 1931]. Carrelli was one of the three winners of the competition *Dissertatio Critica circa theoriam quantorum in physica*, launched by that same Academy in 1929, on the occasion of the priestly jubilee of Pope Pius XI. The Academy, chaired by the Jesuit Giuseppe Gianfranceschi, had put a 10000 lire prize for the competition: half of it went to Gleb Wataghin (1899-1986), while Antonio Carrelli and Paolo Straneo (1874-1968) shared the second half[10] Carrelli distinguishes three periods of development of the new physics:

- the *preparatory period*, which goes from the *first statement of the idea of discontinuity* [Planck 1900] to the *first formulation of Bohr's theory* [Bohr 1913];
- the *period of theoretical spectroscopy*, which begins in 1914 and ends in 1925, with the first works on quantum mechanics by Werner Heisenberg and Louis De Broglie;
- finally, the *period of quantum mechanics*, which Carrelli refers to as still in full development.

In his memory of 1931 Carrelli critically discusses the development of experiments and models born within the new physics, also describing and comparing the mechanics of matrices and Schrödinger's theory, and analyzing the "*relationships between the two versions of quantum mechanics*" [Carrelli 1931, p. 174]. Carrelli's demonstration of the equivalence of the two formulations follows: "*from knowing the quantities in a formulation, you can move on to determining the quantities in the other one*" [Carrelli 1931, p. 176]. Carrelli also published an essay addressed to general audience - *The Quantum Theory* [Carrelli 1932] - in which he gave a detailed account of the contemporary knowledge about the structure of matter, without the use of formulas. The first notes available from the course of Carrelli are the ones corresponding to the academic year[11] 1933-34, followed by the lectures collected by the graduate students Bianca Scognamiglio and Paola Tulipano and published in 1936 [Carrelli 1936]. The 1933-34 lectures include a first part dedicated to restricted relativity, which ends with the discussion of relativistic dynamics. The second part deals with subjects of statistical physics. The quantum theory of specific heats (Einstein-Debye theory) appears at the end of the 1936 lecture notes, while the second part of the 1942 lectures [Carrelli 1942] concerns radioactivity and atomic structure, and includes the theory of the planetary atom[12].

---

del principio di Nernst, 5 (1928) 341-346; *Le nuove concezioni statistiche*, 5 (1928) R1-R14; *Sull'allargamento delle righe per risonanza*, 6 (1929) 281-288; *Aspetti dell'indagine fisica*, 6 (1929) R45-R54; *La teoria dei quanti di luce*, 6 (1929) R77-R90.

[10] Experimental physicist, with a deep attitude to theoretical issues, Gleb Wataghin was in charge of the course of rational mechanics in Turin, at the time of the award. He would emigrate to Brazil in 1934, accepting an appointment at the University of Sao Paolo, and would later return to Turin as full professor of experimental physics, after holding a chair of physics in Sassari (1939/42) and of theoretical physics in Padua (1942/43). Paolo Straneo was full professor of Mathematical physics in Genova since 1928 and starting from the academic year 1936/37 held also the course of theoretical physics, on assignment.

[11] Prof. Roberto Raimondi (Roma Tre University) made kindly available to us his personal copy of. Carrelli's lecture notes mentioned here. The 1933/34 lectures are handwritten and do not show the name of any typography or publisher.

[12] The theoretical physics lectures published in 1937 are entirely dedicated to classical thermodynamics. The 1941 lectures collected by the graduate student Laura Mercogliano are devoted entirely to the theory of relativity. In the theoretical physics lectures published in 1942, again edited by Mercogliano, there are three chapters focused on radioactivity and atom structure, starting from the treatment of cathode rays and the determination of the

It is interesting to note that atomic phenomenology and its interpretation in the context of Bohr-Sommerfeld's old quantum theory represent the topics of the first lectures of Ettore Majorana's course in Naples in 1938, largely borrowed from the course held in Rome by Fermi in 1927-28 and attended by Majorana himself [De Gregorio, Esposito 2007]. Therefore, apart from the very short presence of Majorana, notions of quantum mechanics appeared in Naples in the lectures on theoretical physics only in the 1940s, a delay that reflects Carrelli's preference for topics related to the structure of matter and statistical mechanics.

5.2 Rome

As for the first reception in Rome of the old quantum theory, we already mentioned that in 1909 Corbino wrote an article in *Il Nuovo Cimento*, entitled *The atomistic hypothesis of radiant energy* [Corbino 1909a]. In the same journal he also published an extract from a letter to Tullio Levi-Civita: *On the corpuscular nature of electric radiation* [Corbino 1909b]. His research activity in the following years was not oriented on quantum physics, but we have already underlined the importance of his political action to promote the formation of a modern physics school in Rome. Also significant is his article *The present-day crisis of physics*, which appeared in 1927 in *Il Nuovo Cimento* [Corbino 1927].
Before Fermi, notions of quantum theory were present in Rome in the complementary experimental physics course held by Antonino Lo Surdo (1880-1949). In January 1919, Lo Surdo had obtained the chair of complementary physics at Sapienza University in Rome. From the lesson records of 1919, one learns that his first course mainly focused on physical optics[13], but already from 1919-20 his lectures included new topics[14]: "*the experience with Michelson's step spectroscope and the observation of the Zeeman phenomenon, emission and absorption (Kirchhoff's law), the black body*".
The lectures of the academic year 1920-21 are enriched with topics of atomic spectroscopy and quantum theory, from an experimental and phenomenological point of view[15]. They include "*Balmer series, Kayser and Runge and Rydberg formulas, relations between the spectra of the elements of the same group, the electrical analogue of the Zeeman phenomenon (today known as the Stark-Lo Surdo effect), experiences on discharge, cathode rays, positive rays, determination of the relationship between charge and mass of the electron (Wien experience), GP Thomson's experience on the hydrogen spectrum, radioactive substances, beta and gamma rays, alpha rays, radiant emanation and radioactive constant, radioactive equilibrium, average life and properties of radium, from uranium to radium for subsequent disintegrations*". In the academic year 1922-23 the course changed its name in "Higher physics and complements of physics". The experiences on electromagnetic phenomena prevailed, in particular those on the induction and mobility of ions in the electric field, but topics such as Bragg's theory, the X-ray spectrometer, the Moseley law, the Planck hypothesis and

elementary electric charge. The first four chapters of Carrelli's lectures usually deal with the physics of gases and liquids, the kinetic theory of solids and the Brownian motion.

[13] In the (complementary) experimental physics lectures for to the academic year 1918-19, Lo Surdo discussed, among the topics of his course, the following, as described in the lesson records preserved in the Rectorate Archives of Sapienza University of Rome: Fresnel mirrors, Young's experience, Newton's rings, Michelson interferometer, diffraction from slits, dispersive and resolving power of a lattice, circular and elliptical polarization.

[14] *Libretto delle lezioni di fisica sperimentale complementare dettate dal Sig. Prof. Lo Surdo Antonino nell'anno scolastico 1919-1920*, Rectorate Archives of Sapienza University of Rome.

[15] *Libretto delle lezioni di fisica sperimentale complementare dettate dal Sig. Prof. Lo Surdo Antonino nell'anno scolastico 1920-1921*, Rectorate Archives of Sapienza University of Rome.

the limit of the continuous X spectrum are also treated. In the academic year 1925-26 the course program still included the study of radioactivity, as in 1920-21, and treated also the experiences of Rutherford and Geiger to count alpha particles, the study of the nature of alpha particles and of helium emanated from radium[16].
With the establishment of the chair of theoretical physics in Rome, the relative course began already from the academic year 1926-27. The lectures of theoretical physics held by Fermi in 1926-27 and 1927-28 followed the evolution of the first quantum theory (the topics added in 1927-28 are highlighted below): gas physics and equipartition theorem of the energy, cathode rays and electric charge determination, notions of radioactivity, the positive nuclei and the atomic model of Rutherford, Maxwell's equations, the photoelectric effect and the quantum theory of light, the Compton effect, the energy levels of the atom and the Bohr mechanism for the emission and absorption of light, the spectrum of the hydrogen atom, the Balmer series, the Rydberg number calculation, the Stark effect, the normal and anomalous Zeeman effect, Bohr's magneton, the quantum theory of the Zeeman effect and the experience by Stern and Gerlach, the hypothesis of the rotating electron, the quantum theory of the hydrogen atom, the He spectrum, the structure of the spectra of alkaline metals[17]. Only from 1928-29 did Fermi include wave mechanics in the course, which in his *Introduction to atomic physics* occupies the last of the ten chapters [Fermi 1928].
Among the most active scholars of quantum theory in Rome we find a Jesuit, Giuseppe Gianfranceschi (1875-1934), professor of astronomy (1915-26) and physics (1921-22) at the Gregorian University and president of the Pontifical Academy of Sciences since 1919 to 1934. It is not by chance that, under his presidency, the Academy launched the aforementioned competition for the best critical dissertation on new physics, won in 1931 by Wataghin, Carrelli and Straneo.
Gianfranceschi had an extremely critical attitude with respect to quantum physics since its first formulation and continued to follow its developments carefully even during the 1920s. He himself published some articles on *Il Nuovo Cimento*, concerning the interpretation of spectroscopic data and the structure of the atom[18]. Gianfranceschi took part in the International Congress of Physicists, which was held in Como in 1927, 100 years after the death of Alessandro Volta. The congress was destined to become famous, as it brought together many of the protagonists of the new physics. Here Gianfranceschi could listen to Bohr introducing the new concept of complementarity. At the congress he also presented his personal reflections in the discourse *The physical meaning of quantum theory* (Bologna 1928). His most mature reflections on new physics are contained in *Chapters of contemporary physics* (Rome 1932), in which he recognized the impossibility of describing some phenomena within the models and theories of classical physics, but insisted that there was still no adequate theoretical framework to explain them. One must not forget the presence in Rome of Ettore Majorana, a most gifted and acute theorist. Besides his remarkable theoretical contributions[19], he was eager to teach and presented very original programs for three

[16] *Libretto delle lezioni di fisica superiore e complementi di fisica dettate dal Sig. Prof. Lo Surdo Antonino nell'anno scolastico 1922-1923*, Rectorate Archives of Sapienza University of Rome.

[17] *Libretto delle lezioni di fisica teorica dettate dal Sig. Prof. Enrico Fermi nell'anno scolastico 1926-1927* and *Libretto delle lezioni di fisica teorica dettate dal Sig. Prof. Enrico Fermi nell'anno scolastico 1927-1928*, Rectorate Archives of Sapienza University of Rome.

[18] G. Gianfranceschi published in *Il Nuovo Cimento* the following papers concerning the new physics: *Sulle cause d'allargamento delle righe spettrali*, 18, 1919, pp. 57-72; *Sulla distribuzione dell'energia nello spettro normale*, 3, 1926, pp. 259-266; *La struttura dell'atomo*, 3, 1926, R55-R61; *La struttura dell'atomo e l'emissione della luce*, 3, 1926, R71-R78.

[19] Papers by Ettore Majorana published in *Il Nuovo Cimento*: *Sulla formazione dello ione molecolare di elio*, 8, 1931, pp. 22-28; *I presunti termini anomali dell'elio*, 8, 1931, pp. 78-83;

different, unprecedented theoretical courses, to be carried out as *libero docente* (*free lecturer*). The titles he gave to these totally new planned courses were *Mathematical methods of quantum mechanics*, *Mathematical methods of atomic physics*, *Quantum electrodynamics*, respectively for the academic years 1933/34, 1935/36 and 1936/37 [De Gregorio, Esposito 2007]. However, unfortunately these courses were never held. After Fermi's departure in December 1938 and a brief period in which the theoretical physics course was entrusted to Bruno Ferretti[20] (1913-2010), the Roman chair of theoretical physics passed in 1940 to Giancarlo Wick, who thus left Padua and who held the course until 1946, when he left Italy to move to the United States.

5.3 Florence

It was a somewhat privileged seat, first for the early presence of Fermi then for that of Persico. One should remember that Lo Surdo made the discovery of the effect that bears his name in 1914, when he was an assistant to the physics cabinet in Florence. Enrico Persico held the theoretical physics course in the academic years[21] 1926/27, 1927/28 and 1928/29. In the first year, the course covered only topics of classical electromagnetism, while in 1927/28 Persico introduced several topics of (old) quantum physics: Rutherford's atomic model, Planck's theory of the black body, Bohr-Sommerfeld quantization, spectral series, Pauli principle. Finally, in 1928/29 the new quantum mechanics was also introduced (lectures 47-64). In 1929 Persico published the course notes with the title *Lectures on wave mechanics* [Persico 1929], collected by Bruno Rossi (1905-1993) and Giulio Racah. After Persico's departure for Turin, the theoretical physics course was entrusted to Bruno Rossi from 1931/32 to 1933/34, and subsequently to Giulio Racah from 1934/35 to 1937/38 and to Tito Franzini (1902-1989) from 1939. In the academic year 1943/44 the course was assigned to Mario Girolamo Fracastoro (1914-1994), and from 1944/45 onwards to Simone Franchetti (1907-1990), who became full professor of experimental physics in Florence in 1949.

5.4 Bologna

Quantum theory enters institutional courses at the Bologna University with Giulio Cesare Dalla Noce[22] (1885-1969), who held the theoretical physics course on assign-

Teoria dei tripletti Píncompleti, 8, 1931, pp. 107-113; *Atomi orientati in campo magnetico variabile*, 9, 1932, pp.43-50; *Teoria relativistica di particelle con momento intrinseco arbitrario*, 9, 1932, pp. 335-344; *Teoria simmetrica dell'elettrone e del positrone*, 14, 1937, pp. 171-184. Other publications by Majorana: (with G. Gentile jr), *Sullo sdoppiamento dei termini Roentgen ottici a causa dell'elettrone rotante e sulla intensità delle righe del Cesio*, Rendiconti dell'Accademia dei Lincei, 8, 1928, pp. 229-233; *Reazione pseudopolare fra atomi di Idrogeno*, Rendiconti dell'Accademia dei Lincei, 13,1931, pp. 58-61; *Über die Kerntheorie*, Zeitschrift für Physik, 82, 1933, pp. 137-145; *Sulla teoria dei nuclei*, La Ricerca Scientifica, 4(1), 1933, pp.559-565 (Italian version of the previous paper).

[20] Fermi himself had recommended Ferretti as his substitute for the theoretical physics course during his "temporary" leave. Therefore, the Science Faculty of Sapienza University entrusted Ferretti for the academic year 1938/39 [Amaldi 1979].

[21] Persico E., *Programmi dei corsi*, Annuari dell'Università di Firenze per gli A.A. 1926/27, 1927/28 e 1928/29.

[22] Dalla Noce published in *Il Nuovo Cimento* two papers on quantum theories: *Sulle teorie quantiche della valenza*, 9 (1932), R185-R203; *Le particelle elementari nella teoria quantica relativistica di Eddington*, 16 (1939), pp. 305-323.

ment[23] at the University of Bologna from 1927. Being an assistant since October 1922, he became *aiuto* (*help*) in 1936 and held the position until his retirement in October 1945. Dalla Noce never got full professorship. In January 1930 he introduced for the first time in his course notions of the new quantum theory, with a lecture dedicated to wave mechanics and to Heisenberg's quantum theory. It is significant that a copy of his manuscript *Theoretical Quantum Physics and Chemistry* [Dalla Noce 1932], preserved in the library of the Physics Department of Sapienza University in Rome, belonged to Enrico Persico and shows a dedication by Dalla Noce to the latter. The assignment of theoretical physics for the academic year 1942/43 was entrusted to Bruno Ferretti, then again to Dalla Noce for the following two years, while for the academic year 1945/46 was entrusted to Gilberto Bernardini (1906-1995), professor of experimental physics, and to Leonida Rosino (1915-1997) for the academic year 1946/47.

5.5 Milan

In the lesson records of the complementary physics course held by Aldo Pontremoli in the academic year 1926/27 (the last one he was able to complete) we find: Heisenberg's quantum mechanics on June 13 and 14, 1927; and Schrödinger's wave mechanics on June 15, one year ahead of Fermi and Persico. After the disappearance of Pontremoli, in the academic year 1928/29 the theoretical physics course was assigned to Bruno Finzi (1899-1974), who in the last five lessons also dealt with wave mechanics and Heisenberg mechanics. Starting from the academic year 1929/30 for a few years the course was taught by Giovanni Polvani (1892-1970), who since 1929 held the chair of experimental physics, but had always also expressed theoretical interests. In 1936/37 the course was entrusted to Giovanni Gentile by appointment. In 1937 the Milan chair of theoretical physics was established and Gentile, the first winner of the second theoretical physics competition, became full professor. When Gentile prematurely died in March 1942, the course was suspended for the academic year 1942-43. It appears instead that in that period Gaetano Castelfranchi (1892-1965) had the qualification of free lecturer (*libero docente*) in Milan. It's interesting to notice that he had been the author of one of the first manuals of quantum physics in Italy [Castelfranchi 1929], re-edited in many subsequent editions, including the eighth one: *Modern physics. Atomistics and nuclear transmutations* [Castelfranchi 1946]. The course was subsequently assigned to Carlo Borghi (1910-1984), in the academic year 1944/45, and in 1945/46 to Carlo Salvetti (1918-2005), who later (1953) won a competition for a theoretical physics chair at the University of Bari.

5.6 Turin

Since 1930 also Turin had its theoretical physics chair, held by Enrico Persico until 1947. Before Persico's arrival, it is worth mentioning, at least concerning research, several papers by Gleb Wataghin (1899-1986) in *Il Nuovo Cimento*[24] as early as 1927. His later works were published largely in the Physical Review. Let's recall that

[23] *Registri delle lezioni di Fisica teorica 1927- 1937*, Rectorate Archives of Bologna University.

[24] Publications by Gleb Wataghin in *Il Nuovo Cimento* in the 1920s and 1930s: *Sopra alcune ricerche sperimentali dirette a stabilire la natura corpuscolare della luce*, 4, 1927; *Teoria della diffrazione svolta in base alla meccanica ondulatoria*, 4, 1927, pp. 32-38; *Determinazione sperimentale dei momenti magnetici degli atomi*, 4, 1927; *Sulla possibilità di conciliare la teoria ondulatoria delle interferenze luminose coll'ipotesi dei quanti di luce*, 4,

Wataghin was winner of half of the *Dissertatio Critica Circa theoriam quantorum in physica* award, launched by the Pontifical Academy of Sciences in 1929, with his memory *Critical Dissertation on quantum theory* [Wataghin 1932].

5.7 Pisa

Schrödinger's mechanics appeared in the course of higher physics held by Luigi Puccianti (1875-1952) already in the academic year 1927/28, and in 1928/29 the formulations of Schrödinger and Heisenberg were also included in the course of mathematical physics held by Orazio Lazzarino[25] (1880-1963). From 1932 to 1936 the assignment of theoretical physics was entrusted to Giovanni Gentile, then from 1936 to 1938 the course passed to Giulio Racah, holder of the related chair from 1937, having ranked second after Gentile in the abovementioned competition. After the expulsion of Racah in 1938 due to racial laws, starting from 1939 for many years (until 1955) the teaching was entrusted to Tullio Derenzini (1906-1988) on assignment[26].

5.8 Padua

In the academic years 1933/34 and 1934/35 the theoretical physics course was entrusted by assignment to Bruno Rossi (holder of the local chair of experimental physics). From 1935/36 to 1937/38 Leo Pincherle (1910-1976) was in charge of it[27], but in 1938 he was purged, like Rossi himself, following the racial laws and emigrated to Great Britain. In 1938 the chair of theoretical physics was established in Padua and Giancarlo Wick, called from Palermo, held it until 1940, and then moved to Rome. In 1942/43 the chair was held by Gleb Wataghin, who had been teaching the physics course for the Faculty of Pharmacy at Sassari. Finally, in 1947 Nicolò Dallaporta became full professor of theoretical physics in Padua, holding that chair until 1962.

5.9 Catania

Starting from the academic year 1935/36, the theoretical physics course was entrusted to Orazio Specchia (1890-1961), holder of the local chair of Experimental Physics. He kept the assignment until 1942, when he moved to Pavia. The course was later assigned to Giuseppe Cocconi (1914-2008), who managed to reach Catania only in 1944 and kept the course until 1945/46.

1927, pp. 315-320; *Sulla teoria dei quanti di luce*, 6, 1929, pp. 41-49; *Sulle relazioni di indeterminazione*, 7, 1930, pp. 392-395; (con Perucca E.) *Localizzazione dell'effetto Volta secondo Volta e secondo le più recenti teorie*, 7, 1930, pp. 337-343; *Sull'elettrodinamica relativistica e sull'irraggiamento nell'urto degli elettroni veloci*, 11, 1934, pp. 635-647; *Sulle relazioni di commutazione nell'elettrodinamica quantistica*, 12, 1935, pp. 290-293.

[25] *Annuari dell'Università degli Studi di Pisa.*

[26] Derenzini published in *Il Nuovo Cimento* the article *La teoria relativistica dell'elettrone*, 11 (1934), pp. 309-328, and some articles on the calculation of the atomic factor: *Il fattore atomico per raggi Röntgen*, 13 (1936), pp. 16-32 and pp. 79-90; *Sul calcolo del fattore atomico di ioni positivi*, 13 (1936), pp. 341-348; *Sul fattore atomico del mercurio*, 13 (1936), pp. 423-425.

[27] Pincherle published several papers on quantum mechanics in *Il Nuovo Cimento* between 1933 and 1937.

5.10 Genoa

From 1936/37 in charge of the course of theoretical physics was Paolo Straneo (1874-1968), holder of the chair of mathematical physics[28]. Let's recall that Paolo Straneo had won a quarter of the Prize *Dissertatio Critica circa theoriam quantorum in physica*, launched by the Pontifical Academy of Sciences in 1929, for his work about quantum theory published in 1931 [Straneo 1931].

5.11 Messina

In 1936/37 and 1937/38 the course was assigned to Antonio Rostagni (1903-1988), a full professor of experimental physics, who in 1938 moved to Padua on the chair left by Bruno Rossi due to the racial laws. In 1942-43 the assignment of the theoretical physics course passed to Virgilio Polara (1887-1974).

5.12 Modena

Starting from the academic year 1936/37, Mariano Pierucci (1893-1976), full professor of experimental physics, held the course officially named *theoretical physics* for eighteen years.

5.13 Palermo

In the academic year 1936/37 the theoretical physics course was entrusted by assignment to Emilio Segrè (1905-1989). Giancarlo Wick was the first full professor of theoretical physics in Palermo, in 1937/38, but in 1940 he moved to Rome on the chair left by Fermi. In 1939/40 and in 1942-43 Edoardo Gugino (1895-1967), ordinary of rational mechanics, took the relative assignment, while in 1940/41 the course was held by Cosimo Cannata (born 1903).

5.14 Pavia

In 1936/37 the theoretical physics course was assigned to Paolo Rossi (1878-1940), at the time professor in charge and free lecturer in Pavia. Subsequently, from 1937/38 to 1941/42, it passed to Rocco Serini, full professor of mathematical physics, selected in the Cagliari competition of 1925, and from 1942/43 to Piero Caldirola (1914-1984), who held the course until 1955.

5.15 Cagliari

In 1937/38 the professor in charge of the course of theoretical physics in Cagliari was Ivo Ranzi (1903-1985), who also had the assignment of experimental physics course. In 1940/41 the course passed to Guglielmo Righini (1908-1978), and in 1942-43 to Giuseppe Frongia (1908-1982), later a full professor of experimental physics in the same university.

[28] Straneo published in *Il Nuovo Cimento* the paper *La teoria dei quanta e i suoi nuovi indirizzi*, 5 (1928), R73-R96.

In conclusion, it is worth noticing that the University of Parma was the only Italian state university that, although providing a degree in physics, did not activate a course in theoretical physics until after the Second World War. From the academic year 1945/46, the course was assigned for several years to Antonino Borsellino (1915-1992), who became full professor of theoretical physics in Genoa in 1951.

6 Conclusions

The outbreak of the new physics - quantum mechanics - prompted the abandonment of the positivist and empiricist legacies widespread in the research activity of Italian physicists. It made it urgent to turn to an investigation approach integrating theory and experiment, the elaboration of predictive models of phenomena and the laboratory practices, in order to keep up with the scientific progress that was maturing beyond the Alps. Apart from the brief but significant experience of the Pisan school during the nineteenth century [La Rana 2019; Battimelli, La Rana, Rossi 2020], in fact, theoretical studies acquired an academic identity among Italian physicists only in the 1920s, with a delay of about half a century compared to the establishment of the first university courses of theoretical physics in Germany.

This change in route was made possible on the one hand thanks to the advent of some extraordinary self-taught young researchers, *in primis* Enrico Fermi, able to follow and actively contribute to the new physics; on the other hand, thanks to the literacy process that began with the creation of the first professorships and the first university courses in theoretical physics, a process promoted in particular by some leading figures in Italian physics and mathematics (Corbino, Volterra, Levi-Civita, Castenuovo). These scientists were able to recognize the young talents who could ferry Italian physics towards a new era and opened the way for them.

We have seen, therefore, how the diffusion of the new physics took place at different times, even after years, in the various Italian universities. The complexity of the training process of a country towards a new scientific *forma mentis* payed off during the second half of the twentieth century, by the many remarkable Italian contributions to theoretical physics in its many and increasing branches. These arguments suggest the decisive importance of the scientific transition triggered in Italy starting from the twenties.

References

Amaldi E. 1979. The years of reconstruction. *Perspectives of Fundamental Physics*, edited by Schaerf C. Harwood Academic Publisher, New York, 379-455

Battimelli G. 2013. Tra fisica sperimentale e fisica teorica: mutamenti nella fisica italiana del primo Novecento. *Quaderni di Storia della Fisica* **18**: 95-105

Battimelli G. 2015. Persico, Enrico. *Dizionario Biografico degli Italiani - Treccani* **82**

Battimelli G, La Rana A, Rossi P. 2020. Masters and students in Italian Physics between the 19th and 20th centuries: the Felici-Bartoli-Stracciati-Corbino case. *EPJ H* **Volume** (number): page numbers

Bohr N. 1913. On the constitution of atoms and molecules. *Philosophical Magazine* **26** (6): 1-25

Boltzmann L. 1905. Josef Stefan. *Populäre Schriften.* Verlag J. A. Barth, Leipzig, 92-103

Born M. 1924. Über Quantenmechanik. *Zeitschrift für Physik* **26**: 379–395

Brunetti R. 1921. Il nucleo atomico. *Il Nuovo Cimento* **22**: 215-241

Brush S. G. 1968. Mach and Atomism. *Synthese. A Symposium on Ernst Mach (Apr. 1968)* **18** (2/3): 192-215

Carrelli A. 1931. La teoria quantistica. Esposizione critica della nuova fisica. *Memorie della Pontificia Accademia delle Scienze* **XV** (II): 1-200
Carrelli A. 1932. *La teoria dei quanti*. Paolo Cremonese Editore, Rome, 1-152
Carrelli A. 1936. *Lezioni di fisica teorica raccolte dalle Dott.e B. Scognamiglio e P. Tulipano*. G. U. F. Mussolini Sezione editoriale, Naples, 1-166
Carrelli A. 1942. *Lezioni di fisica teorica raccolte dalla Dott.ssa L. Mercogliano. Teoria cinetica dei gas e radioattività*. G. U. F. Mussolini Sezione editoriale, Naples, 1-166
Castelfranchi G. 1929. *Fisica Moderna. Versione Sintetica pianamente esposta della fisica di oggi e dei lavori teorici e sperimentali dei maggiori fisici contemporanei*. Hoepli, Milan
Castelfranchi G. 1946. *Fisica Moderna. Atomistica e trasmutazioni nucleari*. Hoepli, Milan
Corbino O. M. 1908. Il fenomeno Zeeman e il secondo principio della termodinamica. *Il Nuovo Cimento* **16**: 124-129
Corbino O. M. 1909. L'ipotesi atomistica dell'energia raggiante. *Il Nuovo Cimento* **17**: 256-264
Corbino O. M. 1909. Sulla natura corpuscolare delle radiazioni elettriche. (Estratto da una lettera al prof. T. Levi-Civita). *Il Nuovo Cimento* **18**: 197-199
Corbino O. M. 1912. La teoria dei quanti e le sue applicazioni all'ottica e alla termodinamica. *Il Nuovo Cimento* **3**: 368-387
Corbino O. M. 1927. La crisi odierna della fisica. *Il Nuovo Cimento* **4**: R161-R170
Dalla Noce G. C.1932. *Fisica teorica: quantica e chimica. A.A. 1931/32*. University of Bologna, Bologna, 1-155
De Gregorio A., Esposito S. 2007. Teaching Theoretical Physics: the cases of Enrico Fermi and Ettore Majorana. *American Journal of Physics* **75** (number): 781
Del Lungo C. 1916. Sulla teoria cinetica dei gas. Note I e II. *Il Nuovo Cimento* **12**: 166-175, 215-230
Dragoni G. 1989. Per una storia della fisica italiana tra la seconda metà dell'Ottocento e la Prima guerra mondiale (1850-1915). *La storia della scienza in Italia*, edited by C. Maccagni and P. Freguglia, Edizioni Bramante, Milano, 306-353
Fermi E. 1924. Considerazioni sulla quantizzazione dei sistemi che contengono degli elementi identici. *Il Nuovo Cimento* **1**: 145-152
Fermi E. 1925. Sulla teoria dell'urto tra atomi e corpuscoli elettrici. *Il Nuovo Cimento* **2**: 143-158
Fermi E. 1926. Argomenti pro e contro la ipotesi dei quanti di luce. *Il Nuovo Cimento* **3**: R47-R54
Fermi E. 1926. Zur Wellenmechanik des Stosvorganges. *Zeitshrift für Physik* **40**: 399-402
Fermi E. 1927. Un metodo statistico per la determinazione di alcune proprietà dell'atomo. *Rendiconti della Reale Accademia Nazionale dei Lincei* **6**: 602-607
Fermi E. 1928. *Introduzione alla fisica atomica*. Zanichelli, Bologna, 1-330
Fermi E. 1929. Sopra l'elettrodinamica quantistica. *Rendiconti della Reale Accademia Nazionale dei Lincei* **9**: 881-887
Fermi E. 1930. L'interpretazione del principio di causalità nella meccanica quantistica. *Il Nuovo Cimento* **7**: 361-366
Garbasso E. 1904. Le scariche oscillanti nei sistemi di conduttori complessi e la teoria elettromagnetica dell'analisi spettrale. *Il Nuovo Cimento* **8**: 344-364, 393-424
Garbasso E. 1905. Le scariche oscillanti nei sistemi di conduttori complessi e la teoria elettromagnetica dell'analisi spettrale. *Il Nuovo Cimento* **9**: 31-53, 113-150
Garbasso E. 1906. Vorlesungen über theoretische Spektroskopie. *Zeitschrift für Elektrochemie und angewandte physikalische Chemie* **12** (36): 694-695
Garbasso E. 1909. La struttura degli atomi materiali. Conferenza tenuta al Congresso di Firenze della Società per il Congresso delle Scienze. *Il Nuovo Cimento* **17**: 117-143
Garbasso E. 1914. Sopra il fenomeno di Stark-Lo Surdo. *Il Nuovo Cimento* **7**: 338-343
Gariboldi L. 2015. Pontremoli, Aldo. *Dizionario Biografico degli Italiani - Treccani* **84**
Gariboldi L. 2020. Il primo concorso di fisica teorica: il caso di Aldo Pontremoli. *Quaderni di Storia della Fisica* **1**: 91-115
Giuliani G, Marazzini P. 1994. The Italian physics community and the crisis of classical physics: New radiations, quanta and relativity (1896–1925). *Annals of Science* **51** (4): 355–390

Graffi S. 2010. Considerazioni sulla grandezza e decadenza dei concorsi universitari in Italia. *Quaderni di Storia della Fisica* **71**: 77-110

La Rana A. 2019. Italian Physicists of all Times: a Biographical Dictionary in preparation. *Il Nuovo Cimento* **42** (C): 239-246

La Rana A, Rossi P. 2019. I Fisici Italiani 2: dal Risorgimento alla Seconda Guerra Mondiale. A-C. *Supplemento Giornale di Fisica della Società Italiana di Fisica* **60** Bologna, 1-113

La Rana A, Rossi P. 2020. I Fisici Italiani 2: dal Risorgimento alla Seconda Guerra Mondiale. D-L. *Supplemento Giornale di Fisica della Società Italiana di Fisica* **61** Bologna, 115-215

Leone M. and Robotti N. 2006. The Entrance of Quantum Mechanics in Italy: From Garbasso to Fermi. *The Foundations of Quantum Mechanics. Historical Analysis and Open Questions – Cesena 2004*, edited by C. Garola, A Rossi and S. Sozzo, World Scientific, Singapore, 225-237

Lo Surdo A. 1914. Sul fenomeno analogo a quello di Zeeman nel campo elettrico. *Il Nuovo Cimento* **7**: 335-337

Lo Surdo A. 1914. Sul fenomeno analogo a quello di Zeeman nel campo elettrico. *Il Nuovo Cimento* **7**: 335-337

Lo Surdo A. 1914. Su l'analogo elettrico del fenomeno di Zeeman effetto longitudinale. *Il Nuovo Cimento* **7**: 344-346

Maiocchi R. 1991. *Non solo Fermi. I fondamenti della meccanica quantistica nella cultura tra le due guerre*. Le Lettere, Firenze, 1-263

Occhialini R.A. 1913. Oscillazioni intratomiche. *Il Nuovo Cimento* **5**: 452-470

Persico E. 1927. La meccanica ondulatoria. *Il Nuovo Cimento* **4**: R17-R25

Persico E. 1928. Recenti punti di vista sui fondamenti della fisica. *Il Nuovo Cimento* **5**: R117-R128

Persico E. 1929. *Lezioni di meccanica ondulatoria*. Filippini, Firenze, 1-134

Persico E. 1930. Sulla relazione E = hv nella meccanica ondulatoria. *Il Nuovo Cimento* **7**: 344-347

Planck M. 1900. Über eine Verbesserung der Wienschen Spektralgleichung. *Verhandlungen der physikalischen Gesellschaft zu Berlin* **2**: 202

Planck M. 1900. Zur Theorie des Gesetzes der Energieverteilung im Normalspectrum. *Verhandlungen der physikalischen Gesellschaft zu Berlin* **2**: 237

Polara V. 1910. Sul potere emissivo dei corpi neri. *Il Nuovo Cimento* **19**: 329-334

Polvani G. 1939. Fisica. *Un secolo di progresso scientifico italiano* **I**. Società Italiana per il progresso delle Scienze, Rome, 329-334

Pontremoli A. 1923. Sul neutrone del Rutherford. *Atti della Reale Accademia nazionale dei Lincei. Rendiconti* **XXXII**: 277-280

Puccianti L. 1912. Una determinazione in misura assoluta della potenza irraggiata dal corpo nero. *Il Nuovo Cimento* **4**: 31-48

Puccianti L. 1912. Un'altra determinazione in misura assoluta della potenza raggiata dal corpo nero. *Il Nuovo Cimento* **4**: 322-330

Reeves Buck B. 1980. *Italian Physicists and their Institutions*. PhD Thesis, Harvard University

Schrödinger E. 1926. Quantisierung als Eigenwertproblem. *Annalen der Physik* **384**: 361-376

Schrödinger E. 1926. An Undulatory Theory of the Mechanics of Atoms and Molecules. *Physical Review* **28**: 1049-1070

Segrè E. 1996. Fermi, Enrico. *Dizionario Biografico degli Italiani - Treccani* **46**

Somigliana C. 1939. Fisica matematica. *Un secolo di progresso scientifico italiano* **I**. Società Italiana per il progresso delle Scienze, Rome

Straneo P. 1931. Intorno alla teoria dei quanti. *Memorie della Pontificia Accademia delle Scienze Nuovi Lincei* **XV** (II): 363-448

Wataghin G. 1932. Dissertazione critica sulla teoria dei quanti. *Memorie della Pontificia Accademia delle Scienze* **XVI** (II): 273-308