THE COPERNICAN-NEWTONIAN UNIVERSE

COMPULSORY. FIRST QUARTER

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The aim of this paper is to present a guide to the subject "The Copernican-Newtonian Universe". Given that the subject is framed in a Master in Philosophy and Modern Culture, the topic of this course is the history and philosophy of science during Modernity. Depending on the professor responsible of the course there is a wide range of topics to deal with. The period is from around 1450 to 1905 or 1914, depending on the historical landmarks that we take as the beginning and the end of Modernity. We will comment on this later.

The topics are not only extensive because we are dealing with around five hundred years of history, but also from the variety of the sciences themselves. The professor can choose to focus on Mathematics, Astronomy, Physics, Chemistry, Biology, Medicine, Natural History, or all of them. And this is only regarding the history and philosophy of the sciences, but there is also the institutional side. The history of institutions is fundamental to the development of science, and a course focused on this aspect is also possible, particularly, since it is during this period that we have designated as 'Modernity' when universities, academies, research institutes and other scientific institutions were developed and, progressively, acquired the structure that they have today. Also the existence of institutions is what in a material and practical sense makes possible that some people devote their professional life to sciences. Entangled with the more internal history of the sciences and also with the institutional there is also the cultural impact of science. Considering the impact that the Copernican Revolution and, in general, the scientific developments that occurred in general culture during this period is other way of approaching the subject.

This paper will try not to privilege an approach over the others, since this is a guide to the student, and the aim is to help the student to be able to tackle the different approaches with the help of this guide. In this sense, the history of scientific developments should be framed within general history, and thus, the student has to be able to relate scientific achievements with historical developments to obtain an ordered sequence of events and to situate them in the adequate historical context. The same happens with philosophical developments. In this course, history and philosophy of science are not conceived separately, and it will be important that the student has a background in the history of philosophy and is competent to establish links between philosophical conceptions and scientific ideas.

As we are well aware that not every student that enrols in this course has a philosophical background, this paper is devoted to both kinds of students, those who have an undergraduate degree in philosophy and those who have not. Along the paper, we will make recommendations for both, and after the description of the contents, we will introduce a list of references.

GENERAL DESCRIPTION OF THE COURSE CONTENTS

1. Preliminary questions

One of the issues that challenge more the students with a non philosophical background in this kind of course is the existence of the course itself. First of all, they are usually puzzled by the title itself —this title also puzzles the students in philosophy and mainly because of the same reasons. They do not really understand what the 'Copernican-Newtonian Universe' is, and they wonder if it is the same universe in which they live in. The students in philosophy have usually a hint about it and they associate this title with some kind of history and philosophy of science, but they mostly do not get why that title instead of a more regular 'history of science' or 'philosophy of science'. One of the points to understand the course is to understand the title itself. The Copernican-Newtonian Universe is not just the particular scientific developments that occurred between Copernicus and Newton, but a vision of the world —a worldview— that was configured during the period that we have mentioned above, i.e. the period of Modernity. So it is not only about a few particular scientific discoveries or theories, but a way to understand the world around us that only twentieth century will overturn. World here is a big word, and it includes of course, nature, but also the place of the human being in nature, her intercourse, limits, abilities and the way this being itself conceives his own knowledge and the knowledge of nature. So, the Copernican-Newtonian worldview determines and reflects how men of this period approach the world. In a certain sense, the Copernican-Newtonian Universe is a synonym of Modernity, but in this course, we will devote ourselves not to every aspect of Modernity, but to those related to the knowledge of nature and thus, to the development of science.

Once the issue of the title is clear, we can come to the second reason why this course puzzles non-philosophy students. Students in philosophy are used to have courses related to science in their undergraduate training, so it comes as no surprise to them —although even after all that undergraduate time, some of them still do not get the relations between science and philosophy. In the usual conception of philosophy in society, it is linked to humanities. Thus, students coming from anthropology, pedagogy, educational sciences or other background do not get what philosophy has to do with science. This is not a difficult issue to explain, and usually, as soon as they get that science has to do with thinking, then it has to do with philosophy.

After the clarification of the nature of the course, its title and its place in the Master Program, the first point in the course's program is to get an idea of what this thing called 'science' is. It is a word of our everyday vocabulary, but very difficult to define. It is easier to think about 'the sciences', and makes more sense to provide a concrete view. But it helps to identify some requirements to the existence of science, some that prevent the student from giving the answer that 'everything a human being does is scientific, from the invention of fire, to the study of atomic particles, or even breathing'. Even if our landmarks are not sufficient conditions for the existence of science, they are necessary, in the sense that if these do not appear, we are talking about a different issue, and not about science. First of all, there has to be a long record of data, picked up during a long period of time and with some concrete purpose; second, there are institutions that preserve and transmit the knowledge obtained from the data; and finally, there are instruments, some kind of technology developed to better collect the data (cf. Ordóñez et al. 2003, 25-26). When the student has this in mind, it is easy for her to understand that there has to be some system of symbols (writing) to collect the data, material support for them, and some social structure to create the institutions in which science is developed, as well as technical developments that make the construction of instruments possible. So, she will be able to identify them in the historical development of science.

After this rough and shallow definition of the conditions under which science operates, another issue emerges, prompted by the previous question about why this course within a Master degree in philosophy. This is the debate between sciences and humanities, or, as from C. P. Snow's famous intervention, the debate over 'the two cultures'. Most of the students admitted to the Master have a background in humanities and/or social sciences. This places the balance usually in biased perspectives in which science is conceived as the 'enemy', simplistically associated with capitalistic regime, the destruction of nature, the underestimation of humanities by the imposition of scientistic cannons, the alienation of individuals because of the industrialized developments that scientific technology has brought to society, and every kind of malignant effect that might be derived from the use of science, and mostly from technology. There are of course exceptions among students who think differently and who are able to conceive separately science from technology, but this is the minority response. So, it is quite pedagogical at this point to try to think about the good effects that scientific and technological developments have brought to society —from toilet paper to the vaccines— but more importantly, some respects in which the dismissal of scientific knowledge leads to uncritical societies and the dangers that the lack of scientific formation carries for health, environment, expert judgment, education, journalism, and society in general. Since the student is already an educated person, it is also useful to help him distinguish that the development of science is not tantamount to that of capitalism, and the logic of environmental destruction. And, why not, to consider that intellectuals are usually public figures in which all of us presuppose a humanistic instruction but never a scientific one, and, in such case, it is humanities the one which is placing science outside culture. An example will clarify this point: in western culture, it is a requirement to consider someone a cultivated person to know who William Shakespeare was, and even to have read one or two of his plays. But a cultivated person can perfectly ignore or not remember Newton's first law or the content of the Pythagorean Theorem. Contrary to what students in this Master tend to think, this places science in a disadvantaged position regarding its place in culture.

This general discussion is useful because Modernity is philosophically known as the period in which men pass from trusting theological powers to trusting their own, and this includes their own knowledge of nature, which is science. Thus, it is helpful to consider science as a part of western culture, in the same sense that the feelings defined in Shakespeare's plays are a part of it, and that there is no need to establish a divide between both, but to consider them as complementary and usually not opposed views.

2. Historical landmarks: the beginning and the end of Modernity

The division of historical time into epochs or ages is, as every student must know by this stage of her instruction an arbitrary one. And although it is difficult to establish the precise moment in which Middle Ages finishes and Modernity begins, some landmarks or particular historical events are helpful to understand that something different, something relatively new, a new worldview is emerging. Just like the Middle Ages, or Antiquity, Modernity is far from being a uniform period. Many changes occur in society from 16th to 18th centuries and even more during 19th. In the course it is important that the student has in mind that epochal variety trying to establish a coherent and contextualized evolution of scientific concepts and institutions. But first of all, from when to when does Modernity last?

There is no single event that marks the end of Middle Ages, but there are three of particular relevance for European inhabitants that mark a point of no return. I will refer to them in chronological order. First of all, 1440 the year of the invention of the mechanical movable printing press. Gutenberg's invention —or introduction into Europe as some historians put it— brought not only the possibility of spreading knowledge because of the cheaper cost of books since them, but the fact in itself that knowledge was accessible to a wider number of people, and then, it made much more sense to learn how to read. The second landmark is 1453 the year of the conquest of Constantinople by the Turks. This marks the end of the Eastern Roman Empire —Byzantine Empire— and the creation of a physical and cultural frontier that will separate Europe from Asia and Africa, and culturally from Islamic people for centuries to come. It also meant the recovery for Europeans of many original Greek works lost since late Antiquity, because the cultivated Christians living in Byzantium who had the chance to escape from the Turks took their books with them, mostly to Italy. The last date is 1492, usually celebrated as the 'discovery of America'. I prefer to put it as the arrival of Christopher Columbus to the western Indies, since it will take a few years until this arrival represents the discovery of a new continent for Europeans. This trip is a symbol of the consequences that the Portuguese and Castilian navigators brought to western culture. After those trips, there will be a new world, a new sky never seen by western men, a new dimension of the earth, its measurement, the corroboration that it is spherical, the existence of different continents, and many other things, too many to be described in here. Less known to non-Spanish students is the fact that 1492 is also the year in which the last Muslim European kingdom fall: the kingdom of Granada. In January 1492 the Castilian queen Elizabeth I, called 'the Catholic', and her army conquered the last Muslim kingdom in the Iberian Peninsula, ending thus the Islamic presence in European territories. That very same year, Muslims and their culture will be expelled from the Spanish territory, marking the end of the cohabitation –not always pacific –that happened since the arrival of Muslims to Europe in 711. With the expulsion of Islamic culture, much was lost from a cultural point of view, in particular, the fruitful exchanges that since around 1000 had taken place. The lost will not only be for Europe, but also for Islamic culture, because it will be conceived as the 'enemy' since then and given the Mediterranean rivalry between Europe and the Turks, Islamic people will become isolated from Europe representing each of them the enemy for the other.

These are three important events, but in any case, the beginning of Modernity could be rightly placed by 1450 (cf. Lindberg 1992, 235), when the cultural and literary developments that we now call the Renaissance were certainly ongoing.

Regarding the end of Modernity, the transition from 19th to 20th century is usually seen as another epochal change. Scientifically, many people placed in 1905 the beginning of new era, because of the publication of Einstein's paper on the special theory of relativity, but historically considered, that does not mark a change, and it was not automatically accepted even within the scientific community. Only after Eddignton's eclipse of 1919 did Einstein become a pop-culture figure and could the new theory (general relativity) be considered as a new scientific worldview.

The periodization of history is complicated and very relative to different countries, even for western people. In Spain, when referring to history we usually consider the French Revolution of 1789 as the beginning of Contemporary Epoch, but when we think about it philosophically, it still belongs to Modernity. In American contexts, it is 1945 —the end of World War II— what marks the start of Contemporary Period. We will choose here the philosophical consideration and see 1914, the beginning of World War I as the end of Modernity, since it marks the commencement of international policy beyond European borders, and in philosophical, scientific and political respects a new way of thinking, a new worldview. Many are the testimonies of the men and women that lived before and after that war and considered themselves as belonging to a world that no longer existed, some among the famous are Stefan Zweig or Philip Roth, but that feeling was shared by the generation that lived between around 1890 and 1950. The world became really global for most of the population at that period. And we can imagine that a similar kind of feeling —with the historical difference given by the contextual disparity— might have been that of men around 1600 who contemplated the disappearance of the traditional geographical borders because of the emergence of new world maps and of the infallibility of the church power by protestants and men of science.

3. State of the art

Once the historical period is established, it is important that the student has an idea about what he is supposed to know before starting the consideration of scientific ideas during Modernity. The student must be aware of what scientific or natural worldview existed before the Copernican-Newtonian Universe. Thus, he has to be familiar with Ptolemaic astronomy and the Christianized version of the Aristotelian cosmological and physical conception. Usually, the students in philosophy tend to know about both conceptions, but they must remember the conflict between astronomy on the one side and cosmology and physics on the other, the instrumental conception of astronomy which many astronomers had since the work of Ptolemy and the technical problems that the epicycles, deferents, eccentrics and equants posed to an Aristotelian structure of the cosmos. The students without a philosophical background might very well never have heard of these concepts. It is their task to become acquainted with them. Kuhn's *Copernican Revolution* is a good guide to the state of the art in this topic.

Regarding Aristotelian physics, most students of philosophy have an idea about the theory of the elements and their natural motions, but even if they have read the *Nicomachean Ethics* —considering the best case scenario—, they have never opened the *Physics*, *On the Heavens* or *Meteorology*. It is time for them to do so. The same for the rest of the students, who probably have heard about the relevance of Aristotle for philosophy but have never held in their hands a book by him. Reading philosophy is a practice, it requires the ability to get used to different forms of writing at different times, different styles, like dialogues, treatises, confessions, papers, even novels, and it might well be very difficult for people not used to it, but since this is a Master in philosophy, it is unthinkable for people who want to graduate on it to not be able to read any kind of philosophical text, at least translated into their own language. Probably it will be enough to read the third book of *On the Heavens* and the forth book of *Physics*. There they have the essential concepts to tackle the cosmological and physical conception that was on fashion when Copernicus published his work. It will also be helpful to be familiar with the kind of institutions in which Greek philosophy of nature or science developed: the Academy and the Lykeion for the classical period and the Library and the Museum of Alexandria for Hellenistic science.

The Greek background is necessary to understand the astronomical and cosmological changes that the Copernican revolution brought about, but it is not enough. The student must at least have a hint about the precedent period, i.e. Middle Ages and its social and cultural structure as well as its conception of nature. It is quite useful to be aware of the developments of Arabic science, and the Arabic work on translation of Greek texts since this will help to make a picture of the cultural background available in Europe when Copernicus published his work. So, the developments in Arabic astronomy and medicine are particularly relevant for this aim (Lindberg 1992 is a good source for this). Regarding Christian Europe, it is convenient to know about the teaching of the Liberal Arts, the predominant cosmological view present in the Timaeus until 12th century, and the entrance of Aristotle's philosophy in the educational curriculum from around 13th century, and the criticism that the Aristotelian condemnations of 1210 and 1277 brought against this philosophy, leading to the creation of alternatives such as the impetus theory, which will have an impact in Galileo. Also from the institutional point of view, knowing the foundation, structure and expansion of medieval universities is important in order to be acquainted with the context in which science or natural philosophy was developed.

Finally, in order to understand some of the philosophical changes that Modernity will consider, like the questioning of Ancient knowledge or the overthrown of traditional authority, it is important to consider the contribution of Portuguese and Castilian navigation. The Turkish dominance in the Anatolian peninsula interrupted the commercial exchange with the East, it disrupted the Silk Road. Europeans have usually looked to Asia as a place of exotic richness, thus, in European courts and in noble families, the sumptuous merchandise brought from China and the Indies was very appreciated. However, the Turkish dominance made the Silk Road impassable. Also the Italian customs duty, given their dominance in the Mediterranean made the merchandises much more expensive than they usually were. So, Portuguese started to look for a route to the Indies through the ocean, circumnavigating Africa. Their first success was the crossing of Cape Bojador in 1421, learning new ways to navigate and going southern than any other European had before. They reached Southern hemisphere in 1471, contemplated a new sky and conducted navigation guided by 'the Crux', also known as 'the Southern Cross'. In 1488 they enter the Indic Ocean for the first time. For the Castilian side, in 1492 Columbus arrived to the western Indies, his purpose was to arrive to the eastern Indies, but after his third trip in 1500 it was clear that he did not. In 1507 the name America was used for the first time to designate those new lands. And it appeared as a new continent in Mercator's planisphere of 1569.

The amount of knowledge required to produce those achievements, in particular from the technical side but also from the theoretical one —new cosmography, new descriptions of the heavens— certainly had an impact in Modern science. Copernicus quotes the trips of the Portuguese and of the Spaniards in the first chapter of his *De Revolutionibus*. This means that it also had an impact in the new way of thinking. Many questions arise as a consequence of these trips. But there is one philosophical question that provokes an epistemological reflection: if, geography, the sky, the earth, plants, animals and other astonishing new things were not as the Ancients thought they were, why would the heavens be ordered like Aristotle thought they were? If Ptolemy was wrong in his geography, would it be impossible that he might also be wrong in his *Almagest*?

This summarizes the state of the art of science in 1543, when Copernicus published his work and passed away a few days after. Once familiar with those topics, the student is ready to enter into modern science, just like Copernicus was.

4. Early Modern Science

The issue of periodization appears also here. We will chose as landmark the year of the French Revolution, 1789. So we will consider the period from 1543 to 1789 as the 'early Modern' and from 1789 to 1914 as late Modern. So, 16th, 17th and most part of 18th century will be taken as the first period of Modernity.

Our point of departure is the astronomical revolution and the work of Copernicus. Of course, Copernicus never intended to provoke a 'revolution', in the sense of a drastic change of the way of thinking. His main purpose was an astronomical reform that led to a better understanding of the order of the heavens more adequate than that of Ptolemy and respecting the principles of circularity and uniformity that eccentric and equants violated. It is important to understand Copernicus philosophical frame and the Pythagorean and Platonic influence that he received, as well as the technical reasons to reform astronomy, in order to elaborate a new calendar that fixed some important dates of the year, such as the equinoxes, on which depended the celebration of some movable religious festivities, such as Easter. When Copernicus transformed the Earth from being the centre of the Universe into a planet, he might very well not have been completely aware of many of the consequences that this fact prompted, but the case is that it did have consequences in the way of conceiving the order of the heavens, natural science and the way of thinking.

From the point of view of natural science, particularly physics, it is important that the student understands the necessity of a new physics for an Earth in motion. A movable Earth is not compatible with Aristotelian physics, and although the defenders of the Copernican view will have to overcome many difficulties and will have to reply to many objections, they will succeed in developing a new physics compatible with the new worldview. The three main characters in the story of the development of the new physics are Galileo, Descartes and Newton. But before them, some others have to contemplate the reality of the Copernican system. Among these, Thomas Digges, William Gilbert and Giordano Bruno are from the first generation of Copernicans, and Kepler from the second, like Galileo. These men accepted the consequences of the motion of the Earth physically and cosmologically, and did not consider it as an astronomical device. The same happened to Kepler, for whom Copernicanism is a point of departure in all his astronomical considerations and thus, transforms astronomy into celestial physics, being the first to question if celestial bodies turned into their orbits because of the attraction of a central force emanated from the sun. Here the philosophical background is also important, and besides acknowledging the mathematical harmony described by Kepler's laws, it helps to understand his quest for those harmonies. It is important that the student is able to recognise the basic astronomical concepts and to understand the meaning of the laws. An important piece of knowledge to properly appreciate Kepler's sources is to get familiar with the contributions of Tycho Brahe. Not only his more or less known cosmological and astronomical system, but his emphasis in the obtaining accurate observations and his new and continuous method of making astronomical observations. He was the best observational astronomer of Europe at the time, and Kepler realized the relevance of having accurate observations to explain the true system of the world.

After Kepler we turn from astronomy into physics and come to Galileo's contributions. The introduction of the telescope for astronomical observations produces new phenomena never seen. Also the consideration of the relativity of motion and the possibility of shared motions within a system is fundamental to seriously consider the motion of the Earth and the objections about the perceptibility of this motion. It paves the way for the inertial physics that will be fully developed in the work of Newton, with the help of the previous considerations of Descartes. In fact, Descartes presents the first synthesis in which he explains physics, cosmology and astronomy in a mechanical world, developing in physics the mechanic paradigm that will be a point of no return: never again will physics consider animistic conceptions of nature. The scientific revolution is known to culminate with the publication of Newton's *Philosophiae Naturales Principia Mathematica*, but before Newton's achievement it is important that the student considers the contributions of Robert Hooke, Christian Huygens, and of Newton's contemporary, Gottfried Leibniz. All of these men developed relevant ideas that helped to create the new conception of nature and its knowledge that will prevail during 18th century. In fact, the Newtonian system will not be fully imposed until the Lagrangian and Laplacian developments of the end of 18th century. So, being aware of the variety of views and the sophisticated philosophical systems of nature presented is important to properly grasp the development of Modern science.

Before entering into the 18th century, there are three issues that could be addressed. The first one is the historiographical debate on the scientific revolution. There are many controversial thesis, being Shapin's (2000) the most known, but not the only one. In this respect there is a guide range of possibilities: besides Shapin's thesis that there is not a common method or a common view of knowledge that allow us to talk about the "Scientific Revolution"; we have also Zilsel's thesis about the role of craftsmen and the interaction with erudite men; Merton's thesis about puritan values in a capitalist context; Yates' thesis about the extension and opposition to hermetic and magic doctrines; Duhem's thesis that the revolution started in 14th century in the revolt against Aristotelian physics with impetus theory; Hessen's thesis about the socio-economical roots of Newton's work; Eisenstein's about the transition from writing to printing and probably some more. The student does not need to be familiar with all of them, but she has to know what a historiographical controversy is and why there might be one about the scientific revolution.

The second one is about sciences different than astronomy and physics. We can also speak about an anatomical and medical revolution from the works of Vesalius, Paracelso and Harvey. Here some previous knowledge about Galenic medicine and Aristotle's biological consideration is useful to understand the state of the art of the medical and biological sciences. There are also several developments in biology and botany that might be considered as emergent from the discovery of new lands, together with the role of natural history cabinets as institutions to preserve and transmit this knowledge is worth studying. Concerning biology and the micro-world, the work of Hooke and Leeuvenhoek is worth considering. Other field of interest is alchemy and chemistry. The work of Robert Boyle and his discoveries are very important for the development of experimental science. Here there is a paradigmatic case to study the role of scientific instruments, such as the air pump and the study of a purely experimental phenomenon as vacuum.

Finally, the emergence of scientific journals and scientific institutions like the Royal Society and the Académie des Sciences is the third issue that we want to remark in order to understand the social relations among scientists in this period. Becoming familiar with this institutions and the role they played in the diffusion of ideas and in the ongoing controversies among scientist is part of being aware of the spirit of the time.

If during 17th century there is a wide range of sciences, it is even more complicated when it comes to the 18th. It is useful to read some paradigmatic work about the epoch that grasps the 'spirit' of the time. D'Alembert's preliminary discourse to the *Encyclopédie* is precisely that kind of text. Also, to have a look at the table of knowledge is useful to perceive the classification of the sciences at the time. In that text, one can not only perceive some of the scientific ideas of the time, but also the philosophical frame in which they were developed.

In order to summarize the main developments we can consider some topics: astronomy and cosmology, the exploration of the Earth, spreading of scientific ideas, chemistry, and finally, rational mechanics. In astronomy and cosmology we have to consider the work of the Herschel brothers with the construction of their telescope and the discovery of Uranus. In this field, there is also the reappearance of Halley's Comet as the first big triumph of Newtonian mechanics. Cosmological theories are also abundant during 18th century, philosophers like Immanuel Kant wrote *A general theory of heavens* in which he proposed a theory of a nebula that will later be recovered by Laplace.

The exploration of the Earth is a major concern during this century. In 16th century, Spanish and Portuguese dominated the oceans, the British entered the fight during 17th century, and other European countries, as France, Germany or Holland will join the task during 18th century. By then, the expeditions are no longer strictly commercial or with religious aims and there are professional expeditions carried out by scientists. That is the case of the French La Condamine who enrolled in an expedition to determine the shape of the Earth. The Spanish Malaspina or the British James Cook are also interesting figures who travelled all over the Earth with scientific purposes. A consequence of these navigational developments is the need for accuracy in the measurement of longitude. The development of Harris watch to determine longitude in the sea is a technical outcome linked to the exploration of the Earth.

The 18th is also the century of the spreading of scientific ideas. If the first journals and institutions were created during the previous century, every enlightened country will have their own Royal Academy in this century and many new journals will appear. Enlightened kingdoms will favour the development of sciences and arts and will enjoy the progresses of modern science with public shows, lunches with intellectuals and scientists and will educate their sons. In France, the existence of the Salons for the idle aristocracy and the ambitious middle class will also prompt the admission to scientific culture of a group quite underrepresented until then: women. Women were responsible for many Salons and it was their duty to entertain men. So they had to be scientifically cultivated in order to be able to follow the conversation. There are also cases of educated women without a explicit connection to salons, as is the case of Émilie du Châtelet the French translator of Newton and a commendable natural philosopher very understudied.

Within this climate of diffusion of scientific ideas, we can consider the particular case of Spain. There is a European controversy going on during this century regarding the state of science in Spain. Given that this Master course is taught in a Spanish university, it will be useful to know the state of the art of Spanish science and one of its most famous controversies. Feijoo engaged in a discussion with some French scholars who have written an article about Spanish science in a new encyclopaedia. This debate allows a comprehension about myths and realities about the state of scientific research in Spain and how it was seen by other European countries.

Going on with the sciences, one can say that the 18th century is the century of chemistry. The debate about phlogiston and the beginning of oxygen chemistry with protagonists such as Lavoisier and Priestly is one of the high points of the century. Also in the realm of experimental sciences, we have to consider the development of electrical phenomena and their popularization, being electricity no longer a 'magical' phenomenon, but a popular one present in popular fairs with public demonstrations as the 'electric child' and so on.

The last quarter of 18th century saw the development of rational mechanics. It had already begun with Euler and it will continue in the work of the Bernoullis, and will culminate in Lagrange's first edition of *Analytical Mechanics* in 1788. This is a transformation of the Newtonian system, the passing of Newton's mechanics to Newtonian Mechanics. The disappearance of geometric figures and of philosophical foundations of mechanics in Lagrange's work marks a new way of writing mechanics. Lagrange thought that the calculus and thus, mathematics itself was enough to serve as a foundation to rational mechanics, so there was no need of a further philosophical discussion about the elements of mechanics, such as time, space, mass or force. These elements are used as part of the calculus but not discussed as foundations of mechanics. The Lagrangian decision marks a new philosophical perspective that will be followed in 19th century, and continue nowadays.

Within the domain of mechanics, we have also to mention Laplacian celestial mechanics and the introduction of perturbation theory. Laplace is in fact the culmination of the Newtonian conception of nature, in which everything must be explained as the interaction between masses in motion and God becomes a useless hypothesis. Laplace's is the perfect mechanical universe and as such, Laplacian physics will be a new research program that will be developed and will fail during 19th century.

5. Late Modern Science

Lagrange and Laplace are contemporaries of the French Revolution, and so their work marks the end of the 'early Modern' period and the beginning of the 'late Modern' one. There are many issues of relevance in this period and we our aim here is to shown only a general overview of events related to different fields. But before entering into particular developments, it is important to make some general considerations. 19th is the century in which science and philosophy will definitely become distinct categories. During 19th century the category of natural philosophers will be replaced for that of scientist, although that has varieties depending on the language considered. But 19th is the century of professionalization and institutionalization of scientific activity. In that century it will become a possibility to make a life in science, i.e. to be a scientist as a job. In order for that to be possible, industries and governments will have to pay massive attention to science and develop funding programs for institutions, in the sense that particular patronage or sponsorship of noble families will not be enough and governments and big corporations will make big investments in science. That will also bring as a consequence the impact of science in universal culture. If, during the previous century enlightened societies will see science as a mark of enlightened men, considered as particulars, during 19th century governments will develop educational programs to in order to reach many citizens and industrialized societies will also become scientific societies. The universities will change their classical structure during the century, dividing the traditional faculty of arts or faculty of philosophy in several different faculties, creating thus the faculties of sciences, of letters, or even dividing the sciences into mathematics, physics, biology, and so on, until they get the structure that we are familiar with today. The institutional side is very important in this century, and it also has national particularities, so general descriptions are no longer possible, but there are two general models to be implanted that later will have local distinctions. The general models are the German and the French. The French will export their model of the great *Écoles* (Polytechnic and Normal) to many countries, and the German will export the division of the philosophical faculty into several departments, first (mineralogy, physics, chemistry) and into several faculties later. Particular cases are interesting to explores, but as this is just a guide, in what follows I will focus on a list of scientific developments in order to provide the student with a conceptual map.

Starting with mathematics one of the first achievements is Gauss' publication of *Disquisitiones Aritmethicae* in 1801. That book will mark the development of Modern mathematics in many ways. The development of number theory during 19th century depends largely on Gauss' ideas in this book. Later on the century also in the domain of Number theory the early development of set theory will arrive with figures like Riemann, Dedekind, and Cantor, with the introduction of transfinite numbers and the new mathematical possibilities that all these ideas will open. 19th is also the century of non-Euclidean geometries which will overturn more than twenty centuries of Euclidean dominance opening scientific and philosophical debates about the reality of space and the proper geometry to describe it which will connect geometry and physics until the advent of Einstein's General Relativity. Within the domain of applied mathematics, we have to consider the problem about the stability of solar system that led Poincaré to the development of the early theory of dynamical systems and to acknowledging of the sensibility of initial conditions which during century will become defined as chaos theory.

There are also big achievements in astronomy, such as Gauss discovery of Ceres, a planetoid in the solar system, also in 1901 and the measurement for the first time of the parallax of a star —61 cygni— by Wilhelm Bessel. This measurement will confirm the big distance of stars, a theory put forward by Copernicus and finally now confirmed. In the field of observational astronomy Schwabe will establish the period of solar spots, and its connection to magnetic storms causing the aurora borealis, a phenomenon that had puzzled scientist for years. But probably one of the most famous achievements is the combination of positional and observational astronomy that brought the discovery of the planet Neptune by the calculus of Adams and Le Verrier and the observations of Galle in 1846.

This is also a century of great changes in physics. It starts with the experimental developments of wave theory of light with Fresnel, and continues with the conservation of energy, developed in the works of Joule, Helmholtz, Mayer and Clausius. It is quite interesting that the background of these men was not alone physics, but also medicine and physiology, becoming this discovery a interdisciplinary one. In the field of optics and physics we have to mention Maxwell's electromagnetic theory and Hertz's experimental confirmation of electromagnetic waves. These developments will challenge the mechanistic worldview that had prevailed since Newton and will lead to the problems in electrodynamics that become the basis of Einstein's relativity theory. An important institutional achievement to be highlighted is that in 1899 Ilse Neumann will receive the first PhD in Physics from the University of Berlin, she had to ask a special permission to the Education Ministry to be able to receive it. Women like her will open the path for others to receive graduations and to become scientists, until they had no longer to ask for a special permission to get their degrees.

One cannot speak about 19th century science without mentioning biology. It is the century of the big biological revolution. The most famous event is the publication of Darwin's *On the origin of species* in 1859. But there are other fundamental developments in this field, such as cellular theory developed by Schleiden, Schwann and later by Vicrhow, with the principle 'omnis cellula ex cellula', for which every cellule comes out of another. Also, in 1856 the discovery of human remains in the valley of 'Neander' in Germany will allow the study of past human remains, although it will take years to know that they were from a different species than homo sapiens, but without any doubt, this was a great discovery for biology, physical anthropology and philosophy, since it will open new considerations about the descent of man. Finally, Mendel's genetic research on genetics of peas will bring the laws by which hereditary traces are transmitted, providing genetic foundations to evolutionary theory.

Closely linked to biology, we have to consider achievements in geology, such as the consideration of the age of the Earth, in Lyell's theory, an important point for evolutionary biology or the study of the formation of glaciers by Agassiz, which will alter the image of the Earth as unchanged and static since the moment of creation.

In medicine and physiology the 19th century begins with an open controversy between vitalism and organicism, in which the later will prevail bringing a mechanistic and chemic view of life processes, leaving outside the last reductions of occult forces as principles of life. Pasteur researches on microbes which lead to the famous pasteurization process also had an impact in this debate, as well as Claude Bernard's experimental medicine in which he developed important studies of anatomy in order to understand the function of the organs. In this same field, the same field, the discovery in 1882 of Robert Kochs bacillus of tuberculosis initiated a new way of explaining diseases, conceiving its symptoms, causes, consequences and treatments.

In this series of discoveries and controversies, it is remarkable that some debates were closed by discoveries in fields alien to the original ones in which the controversies were debated. This is the case of the synthesis of Urea and the debate between vitalism and organicism. It was the first chemical synthesis of what was thought as a natural product, breaking the divide between laboratory and nature and closing the hidden principles of living organisms conception. This kind of discoveries and its role in debates from other sciences reminds us of the relevance of interdisciplinary research. Laboratory chemistry will be one of the sciences with more industrial applications. For example, chemical synthesis was also used to discover the synthetic composition of aniline, the chemical compound of purple, a very expensive dye that was until then reserved for royal families because of its weirdness and difficulty to obtain. Chemical dyes will be a prestigious and rewarding industry that will turn it into one of the most polluting industries of our century –although back then, they did not know. Another industrial achievement was the discovery of dynamite which will turn Alfred Nobel into a rich man, and will bring new ways of exploiting the earth resources. But not every chemical developments in this century is related to the industry, some of them are theoretically related. We will remark two: Kirchhoff and Bunsen's development of spectroscopy, in which they discovered that every chemical element is related to certain spectral lines which allowed them to determine the chemical composition of stars and to detect helium. Related to the elements is also Mendeleev's table, in which one can find out an ordered sequence of elements and locate in the free spaces that there had to be others to discover. This reveals an ordered nature at its fundamental level, a possibility to know what is missing, and how to orientate research to determine it.

As the student can see, this is only a guide and an overview of the scientific developments of the five hundred years that Modernity lasts, but more than that, it is a way to explore how scientific and philosophical ideas interact.

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