Raffaele Pisano • Danilo Capecchi • Anna Lukešová
*Editors*

# Physics, Astronomy and Engineering. Critical Problems in the History of Science and Society

*32nd International Congress of the Italian Society of Historians of Physics and Astronomy*
*Roma 2012, Italy*

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# Foreword


## Chris Bissell



**Abstract**. A short personal view is given of trends in the historical, philosophical and sociological studies of science and technology over the last several decades. This is then related to some issues in the history of science and technology that emerged from two specialist conferences in the summer of 2013. An interdisciplinary stance to our subject that combines the best of the history, philosophy and sociology of both science and technology appears to be the most rewarding approach.



Keywords: Historiography, SCOT, SSK, STS



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The five decades since the publication of Thomas Kuhn's (1922–1996) *The Structure of Scientific Revolutions* ([1962] 1970) have seen enormous changes in the historical, philosophical and sociological study of science and technology. Of course, there had been significant developments in the historiography of science before Kuhn, not least Boris Hessen's seminal *The Social and Economic Roots of Newton's Principia* (Hessen 1931) presented at the Second International Congress of the History of Science in London in 1931. Nevertheless, a good case can be made for the work of Kuhn being the major influence on the development of a variety of modern approaches such as "Science and Technology Studies" (STS), the "Sociology of Scientific Knowledge" (SSK), or the "Social Construction of Technology" (SCOT).

The thinking of Kuhn and his successors provoked lively debate in the world of the history and philosophy of science and technology during the final third of the twentieth century, debates that are still active and relevant today. On the technological side, post–Kuhnian scholars in Edinburgh (Bloor [1976] 1991 and others), Paris (Callon 1989; Latour 1984 for example) and most of all, perhaps, the seminal conference at Twente University in July 1984 on the social construction of technological systems (Bijker, Hughes and Pinch 1987), brought new life to the general area of the socio–historical study of science and technology.

While pondering what to write in this foreword, I had the opportunity to attend two significant conferences in July 2013:

(i) A comparatively modest meeting entitled *Making the History of Computing Relevant*, held at the *United Kingdom's Museum of Science, Technology and Medicine* in London[1].
(ii) The huge (over 1700 participants) *24th International Conference of History of Science, Technology and Medicine* in Manchester[2].

I was particularly struck by two specific *calls to arms* made at these meetings.

At the London meeting, the old spectre of technological determinism seemed to have escaped complete exorcism. A number of speakers were concerned that the history of computing, and in particular the story of the development of the internet and the world wide web, was too often

[1] Via: www.sciencemuseum.org.uk
[2] Via: http://www.ichstm2013.com (ICHSTM2013).

presented to the public (not by historians, but by politicians and the media) in an overly deterministic, even whiggish, fashion. Recent advances in information and communication technology, it is all too often said, drive economies, social change, and an ever–improving quality of life. Historians of computing (and of other scientific and technological disciplines) thus have a particular duty to give more nuanced accounts, including finding new approaches to the curating of scientific and technological artefacts and making better use of oral history.

At ICHSTM2013, the presidential address of the *British Society for the History of Science* was given by Hasok Chang. The title of what he called his *deliberately provocative address* was "Putting Science back into the History of Science". Chang looked at a number of recent claims that too much history of science was being carried out by scholars with insufficient scientific knowledge, and he re–visited the perennial issue of whether *history of science* should be a separate discipline, or better incorporated into general departments of history.

At first sight, then, we have what appear to be conflicting concerns. The historians of computing in London were worried about technologically deterministic approaches, which too often ignored the roles of society and culture. Chang appeared to be concerned that the emphasis on culture, society and context might have gone too far in the history of science. This conflict, though, was indeed only apparent. Most significant, perhaps, was the way that Chang identified a number of issues regarding 'the functions of the history of science requiring engagement with scientific content'. These were:

- Understanding the contingent development of scientific knowledge
- Learning about scientific method(s)
- Appreciating past scientific knowledge
- Stimulating new scientific knowledge
- Enriching scientific education
- Bridging the "two cultures" gap
- Challenging the authority of scientists

This is an interesting list, but I would claim that it also applies, *mutatis mutandis*, more generally to the whole of the history, philosophy and sociology of both science and technology. In particular, all these endeavours involve being both a critical friend and an informed external advocate for scientists and technologists. And some of the best writing over the last twenty years on the history and sociology of science and technology has done exactly that: certainly no–one could accuse Harry

Collins and Trevor Pinch (Collins and Pinch [1993] 1998), Thomas Hughes (Hughes 2004) or Steven Shapin (Shapin 1992, 1996), for example, of lacking a rigorous scientific approach or of not being both critical friend and informed advocate of the scientific or technological disciplines that they scrutinised.

Chang also called on his audience to challenge a number of apparent dichotomies, which I'll not list fully here, but the most interesting to me of such dichotomies are the following (some of these are Chang's and some are my own):

*Internalism* versus *externalism*

*Technological determinism* versus *social construction*

*Innovators* versus *users*

*History* versus *philosophy* versus *sociology*

*Science* versus *technology*

Now, many scholars have wrestled with these apparent dichotomies, not least Steven Shapin, Merrit Roe Smith and Leo Marx, David Edgerton (Shapin 1992; Smith and Marx 1994; Edgerton 2006). Shapin's 1992 essay is particularly searching on *internalism* and *externalism*, while Smith and Marx closely interrogate determinism, and Edgerton makes a convincing case for a substantial neglect of users in our disciplines. Now, the reason that there are still heated debates on such issues – or even the occasional scholarly article or measured presidential address – is that each of the above listed terms does have its uses. The mistake, however, is to forget that almost any serious study of current or previous science or technology will have to draw on a wide variety of historical, sociological, and philosophical techniques and stances. It seems to me increasingly irrelevant to try to distinguish too rigidly between the above opposed categories. Nevertheless, even if it can be argued that such oppositions are questionable or tendentious, we must bear in mind the history of debates on such dichotomies, and the fact that distinguished scholars have taken and defended various such positions.

Which brings me, finally, to the papers in this volume.

This *Foreword* is not the place to attempt any synthesis of the wide variety of scholarly work reported here. However, when reading through the abstracts of the papers I was struck by how much of the interdisciplinarity I argue for above is apparent. Clearly, individual papers vary in the precise way that they are informed by the historiography, philosophy and (to a lesser extent) sociology of science. But taken as a whole, the volume is testament to a broad, and thriving, interdisciplinarity in our subject area, as well as an absence of historiographical dogma.

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# Acknowledgments

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It was a pleasure to have all of You in Roma for fruitful discussions and exchanges during the congress, and a pleasant stay in the historical city of Roma.

Lille–Roma–Plzeň, May 2013

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Contributes

# Introduction

## Raffaele Pisano, Danilo Capecchi and Anna Lukešová

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*Dear SISFA Members,*
*Dear New SISFA Members,*
*Dear Friends and Colleagues*

The genesis of such an international and large organizing has deep roots, and the final result has been a long time in the making. In effect, we did not have so much time, but we managed to prepare this event. Despite of that we sincerely hope that the result would satisfy your expectations. When the ideas and production of a work of this nature is carried out over a significant period of time, many friends and scholars become contributors to the working process.

The XXXII International Congress of the *Italian Society of Historians of Physics and Astronomy* (SISFA) was held in the Capital of Italy, Roma. In 2012 the Congress was organized in collaboration with the *Research Centre for Theory and History of Scienc*e (RCTHS) University of West Bohemia in Pilsen, Czech Republic, the *Faculty of Engineering*, and the *Department of Ingegneria Strutturale e Geotecnica*, University of Roma La Sapienza.

We are very honoured that the *L'alto Patronato del Presidente della Repubblica Italiana, European Society for the History of Science* (ESHS), and *National Academy of the Sciences called of XL* (Italy) generously had agreed with their patronage. The SISFA 2012 represents the historical current state of the art of offering new perspectives in history of physics, history of astronomy and related epistemological and philosophical disciplines. SISFA 2012 in numbers was:

| | |
|---|---|
| 75 | Registered participants |
| 11 | Countries |
| 7 | International plenary speakers |
| 7 | International invited talks |

13 Sessions: plenary, invited talks, physics lecture on Higgs Boson, contributes, concert, General Faraday lecture, exhibition of ancient books, exhibition of ancient instruments, SISFA assembly session, D'Agostino tribute, panels, congress dinner, SISFA photo
67 International individual talks

All abstracts and papers submitted have been accepted after peer–reviewed job both in editing and contents. Thus a high and recognized level of contents should be offered, confirming that after 32 years SISFA still offers not only a place for scientific–historical communication, but also a forum for individual and collective research projects to reach, since also in 2012 a wide international audience is expected.

For the second time, after XXVI SISFA 2006, the Congress was held in Rome. Although some of us were also main organizers of 2006, the SISFA organizing committee had provided a new interdisciplinary topic between sciences and engineering:

*Physics, Astronomy and Engineering. Critical Problems in the History of Sciences*

It illuminates issues of major significance: the interaction between historical–epistemological methods of investigations and science and technologies including their integration in foundations of science (pure and applied) and society in the 19th. The general theme of the XXXII SISFA Congress is to analyse historical problems related to the use of physics, mathematics and geometry in applied sciences, to be covered by a series of invited speakers.

A main question would be:

*When and why the tension between mathematics, physics, astronomy, gave rise to a new scientific discipline, the modern engineering?*

Individual contributions are general but correlated with scientific topics and within the following areas:

Anthropology, Archives, Epistemology of science, Foundations of science, Historical epistemology of science, History and epistemology of chemistry, History and epistemology of cosmology, History and epistemology of physics, History and epistemology of science, History epistemology of mathematics, History of architecture, History of astronomy, History of biology, History of chemistry, History of cosmology, History of engineering, History of foundations of science, History of medicine, History of physics, History of science, History of science and science education, History of physics and science education, History of mathematics and science education, History of science and logics, History of science and technique, History of science and technology, History of science, society and industry, History of scientific ideas, History of scientific institutions, History of scientific instruments, History of technology, History of scientific drawing, Museum, Philosophy of mathematics, Philosophy of physics, Philosophy of science, Philosophy of science and science education, Theory of science.

We had the pleasure to offer outstanding plenary lectures given by specialists from various parts of the world.

Particularly Christopher Bissell (United Kingdom) honoured us with a distinguished essay as *Foreword* on Science and technologies studies.

Marco Ceccarelli[1] (Italy) spoke about the history of Mechanism Design. He showed that Mechanism Design has been instrumental for the development of science both as necessary means and dreamed/desired goal. He proposed to reconsider the relationship between Mechanism Design and History of Science and understand them as linked to each other because of the strong relationship between practice and theory in knowledge evolution. His lecture was called *An Outline of History of Mechanism Design in Servicing Science*.

Jean Dhombres (France) gave a special talk on *Ecole Polytechnique during revolutionary and imperial Paris concerning restoration in the education of engineers.* He discussed the dispute raised from different approached to the role of mathematics for applications at *Ecole polytechnique*. While Laplace introduced analytical approach, Monge promoted geometrical one. Dhombres then introduced the ideas of Lazare Carnot, often forgotten in the discussion in the opposition between applied and pure mathematics. According to Dhombres, it also appeals to contemporary questions for the teaching of engineers.

Peter Heering's (Germany) speech *Practicing Practices: The Analysis of Historical Experiment with the Replication Method* was about experiments and their role in creating scientific knowledge. He particularly focused on the question of which skills are involved to perform an experiment, and how are these skills developed. He observed that traces of these skills are difficult to find in classical sources, since this knowledge is not verbalized, and partially even cannot be verbalized. Heering thus presented a methodological approach called "the replication method", which focuses

[1] Alphabetical order.

on redoing historical experiments, including the reconstruction of the historical apparatus and contextualisation of the experiences made during this process.

Radim Kočandrle (Czech Republic) took us with his lecture *The Earth Floats Unsupported in Space* to the ancient times. He opened the problem of the explanation of the immobility of the earth given by Anaximander of Miletus.

Walter Noll (United States of America) in his speech entitled *Physics and Mathematics without Coordinates* pointed out that using coordinates when dealing with conceptual issues is now considered obsolete and more sophisticated mathematical tools are used instead. Although coordinates are still needed when dealing with specific practical situations, more often, Cartesian coordinates are not employed and cylindrical, spherical, barycentric or other kinds of special coordinate–systems are used. Noll in this context mentioned the well–known GPS system as a very sophisticated modification of a barycentric system.

As the title of the lecture *Search of the Higgs Boson at the Large Hadron Collider* implies, Aleandro Nisati (Italy–Switzerland) provided a brief overview of the searches for Higgs boson, which is/was the only missing elementary particle of the *Standard Model* of particles and fields. He focused on the latest results of the search for this particle at the *Large Hadron Collider* (LHC) and recent observation of a new boson with a mass around 126 GeV by the experiments The *Toroidal LHC Apparatus* (ATLAS) and *Compact Muon Solenoid* (CMS) at the LHC. He confirmed that preliminary available data show that this particle is consistent with the boson predicted by the *Standard Model*, although further confirmation will be needed to be sure.

Invited guests offered also very interesting lectures in history of physics and astronomy.

Michela Cigola[2] (Italy) investigated the role played by various missionaries of the Society of Jesus in the development and spread of European scientific and mechanical knowledge in China in the 16th century. She focused on Johann Schreck (1576–1630), a jesuit and a disciple of Galileo.

Steffen Ducheyne (Belgium) was concerned with one of the most influential advocates of Newtonianism on the Continent, the Dutchman Willem Jacob 's Gravesande (1688–1742). Ducheyne closely examined 's

[2] Alphabetical order.

Gravesande's "essentially methodological" Newtonianism and spelled out the details concerning his appropriation of Newton's natural philosophy and methodology in particular.

Salvatore Esposito (Italy) attended the Congress with two lectures to share. With Adele Naddeo (Italy) they reviewed early results of the development of quantum mechanics in 1920s and discussed unknown results obtained almost simultaneously by Ettore Majorana.

Mauro Francaviglia and Lorenzo Fatibene (Italy) reviewed some of the insights about the structures of geometry of spacetime implied by gravitational physics. They focused on several propositions made in the early 70s to revise the structure of gravitational theories. Unfortunately the Eminent Professor, Scholar and Friend Mauro recently passed. Kindly we report a remembership by his friends and collaborators Marcella Palese and Ekkehart Winterroth.

Young Suh Kim (U.S.A.) discussed efforts to synthesize two greatest theories formulated in the 20th Century – Relativity and quantum mechanics. He also offed perspectives of Hegelianism in physics and the ancient Chinese philosophy, Taoism, where two different views can co–exist in harmony.

Agamenon Rodrigues Eufrásio Oliveira (Brazil) examined the development of applied mechanics and industrial mechanics connected with the contributions of French polytechnicians: Lazare Carnot's first general theory of machines and Corioli's first textbook on applied mechanics. These two used the concept of work as a fundamental step to build a general theory of applied mechanics within the framework of Rational Mechanics.

Daniel Špelda (Czech Republic) inquired into a neglected area of research: the history of history of astronomy. Špelda's aim was to discuss the transition from searching for the *true* astronomy in the past to the belief in astronomical progress.

Last but not least, the lectures in the contributes sessions also enabled rich discussion and helped to deepen the scientific knowledge.

Enzo Bonacci[3] (Italy) presented the case of a small size planetarium (40–seat capacity) located in Latina (near Roma), the Livio Gratton, which belongs to the Scientific High School "G. B. Grassi". Bonacci weighted up the managing, cultural, educational and scientific valorization policy of the

[3] Alphabetical order.

Headmaster, which brought over 4000 visitors in less than eighteen months.

The team of Fabrizio Bònoli, Elena Cenacchi, Agnese Mandrino, Raffaella Stasi, and Diego Zuccato (Italy) prepared a speech about the project of the digitalization of the records on scientific and administrative life of the University of Bologna, stored in its Historical Archive of Astronomy.

Giuseppe Boscarino (Italy) analysed the positivistic and post–positivistic solutions of the questions of the nature of science. He argued that the the rationalistic and humanistic approach to making science can establish a modern progressive education in science.

Danilo Capecchi and Giuseppe Ruta (Italy) prepared an examination of the organization of German polytechnic schools. They explain that in Germany, higher technical schools were not well framed within the educational system until the half of the 19th century.

Marco Mamone Capria (Italy) and MariaGrazia Manini (Portugal) examined an example of short historical outline in the introduction of Minkowski's special relativity papers, where he used a name "Lorentz's theorem". Manini and Mamone Capria showed that the indication to contemporary scientists and future historians implicit in this name and its accompanying explanations involved a considerable distortion of the historical evidence.

Mario Centofanti in collaboration with Stefano Brusaporci (Italy) introduced the surveying methods and instruments of Ieronimo Pico Fonticulano (1541–1596), a mathematician, land–surveyor, cartographer, and architect.

Emanuela Chiavoni (Italy) analysed some drawings in relation to the artistic techniques in the Diderot's encyclopedia (first volume, 1751). Pictures created in different techniques (drawing, painting, mosaic, sculpture, etc.) were selected to show the rich interconnections between these different kinds of art.

Vincenzo Cioci and Antonino Drago (Italy) prepared a speech concerning the series of social "laws" Haret suggested in a parallel way to mechanical laws. They investigated additions to this theory, among others an addition inspired by the Carnotian theory of mechanics.

Salvatore D'Agostino (Italy) addressed the problem of the overgrowing disorientation and suspicion among people directed against technical and scientific culture, which is unprepared to face political and social demand of an historical period in which regressive tendencies against scientific progress arise. D'Agostino described the endeavour to solve this problem in Italy.

Alessandra D'Amico Finardi (Italy) described the mathematical principles on which the planimeter works, and then summarized the principal types of planimeters.

Pietro Di Mauro (Italy) presented few reflections and ideas to put together the principle of relativity, foundation of classic and relativistic physics, and the wave–particle dualism, basis of quantum mechanics.

Antonino Drago (Italy) collaborated on several speeches, including those with Cioci, and Pisano. In one of his lectures he also examined Einstein's paper on quanta (1905) and argued that it was indispensable for Einstein to take in account two alternative choices to the Newtonian ones.

In other lecture Drago investigated the insufficiency of Planck's calculations designed to solve the problem of black body theory.

Francesco Maria Ferrari (Italy) begun with Ilya Prigogine's (1913–2003) discoveries about complex systems and attempted to find some preliminary ontological basis for a more adequate understanding of nature, which would take into account its indeterminacy, surfaced as empirical evidence of inner non–linear thermodynamics.

Fernando Bandeira Figueiredo (Portugal–France) explored the beginning of the astronomical scientific activity connected to the Astronomical Observatory of the University of Coimbra (1772–1813). Figueiredo recognized Jose Monteiro da Rocha (1734–1819) as the central personality in the conception, planning and construction of Faculty Mathematics and of the Astronomical Observatory.

Piotr Flin presented research of the team comprising of Hilmar Duerbeck, Włodzimierz Godłowski and himself (Poland). They focused on the main achievements of Ludwik Silberstein (1872–1948), who spent years 1899–1904 as a lecturer of mathematical physics in Bologna and 1904–1920 in Rome.

Hélène Fragaki (France) noticed that the works of Hero of Alexandria (1$^{st}$ c. A.D.) imply that his methodology originated from the Alexandrian engineering tradition of the Ptolemaic period. Fragaki explained the relation between theoretical research and mechanics in 3$^{rd}$ c. B.C., since the use of abstract principles for technical purposes must have been a common practice in the court of Ptolemaic Alexandria.

With Marcella Palese and Ekkehart Winterroth, Mauro Francaviglia (Italy) pointed out that in the context of Noether conservation laws associated with some *variational* invariance of global Euler–Lagrange morphisms of local problems of a given type, the question arises whether we should be interested in conservation laws different from those directly associated with invariance properties of field equations. In this context the authors closely investigated Noether's Theorem.

Arturo Gallozzi (Italy) remembered that the protection of monuments from lighting was a problem that took designers a long time to solve. Gallozzi analyzed one of the first, and most important, installations of a lightning conductor system in Italy, applied to a significant and extended complex of monuments, such as the Abbey of Monte Cassino in southern Lazio.

Dimitra Giannara (Italy) identified the structure of Pirandello's novels as an obvious ringkomposition and suggested to replace the common ring with the Moebius ring. In this way, she tried to deepen the analysis of all Pirandello's novels and uncover the inner structures between the protagonists.

Roberto Lalli (U.S.A.) remembered Ives–Stilwell experiment (1938 and 1941), called after Herbert Eugene Ives (1882–1953) and his collaborator G. R. Stilwell. Lalli stressed out that despite of the great importance of this experiment there are still some shortcomings in the analysis of the complex epistemic factors that led to the fulfilment of the experiment and influenced its reception.

Giovanni Macchia (Canada) appreciated Gerald James Whitrow (1912–2000) for being one of the few authors to have explicitly connected the cosmological issue of the universe's expansion with the philosophy of space. Macchia focused on Whitrow's masterpiece *The Natural Philosophy of Time*.

Federica Maffioli and Gianfranco Medici (Italy) focused in their contributions on count Paolo Ballada of Saint Robert (1815–1888), scientist mainly busy in mechanics and thermodynamics. First, they discussed his work *Receding of the Glaciers* and apprised his meteorological explanation of the phenomenon.

In the latter Gianfranco Medici and Federica Maffioli (Italy) presented Saint Robert's scientific explanation of *The true meaning of a tercet of Dante* concerning four stars forming the constellation of Southern Cross – he showed that the stars of the Southern Cross could be visible to first people but not to Dante due to the astronomical phenomenon called precession of equinoxes.

Flavia Marcacci (Italy), remarking on the handbooks by Blaeu and Bion, introduced Parisian globe maker Nicholas Bion (1652–1733), who – unlike his colleagues who were constructing globes – published several pamphlets, e.g. instruction manual *L'usage des globes celestes et* *terrestres*, where he described constructing globes in a Ptolemaic or Copernican system. This is an interesting and unusual proof of persistent problem of comparison between the two systems of world in 17th century.

Raffaele Pisano (France) with Paolo Bussotti (Italy), brought attention to Kepler's *Mysterium Cosmographicum*. In its final sections, Kepler mentioned a force that could be responsible for the movements of the planets in the sky. Although Kepler's concept of force is not suitable to develop a satisfying mechanics, the idea to provide a dynamical foundation to the kinematical results was revolutionary, if we consider that before Newton's *Principia* the force was usually connected to vitalistic and astrological items.

Further Raffaele Pisano (France) in the collaboration with Antonino Drago (Italy) dealt with the principle of virtual velocities and its role played in Sadi Carnot's science with respect to modern thermodynamics.

Arcangelo Rossi (Italy) outlined the most essential scientific–technological, cultural and institutional frame inside which the passage from the tradition of the 18th century's natural philosophy to the new XIXth century's English science and technology took place. This passage was accompanied by a new development of scientific popularization and vast diffusion of science also linked to immediate productive interests.

Antonella Salucci (Italy) reported on the results of a research experience carried out on a significant body of architectural competition drawings, with the aim to outline an evolution of the Italian architectural language of the early years of the 20th century.

Giancarlo Scalera (Italy) discussed the history and perspectives of variable radius cartography. He also noticed that in the field of constant radius paleogeography many computer codes of automatic mapping was created, but in the variable radius field few tried to reach the same task. These few inspired the construction of a variable radius mapping code at INGV, with which it is now possible to represent *paleopoles*, site–pole segments of meridian, and their uncertainty ellipses.

Cesare Tocci (Italy) contemplated about the evolution that forms by means of which the structural control of the architecture has been historically implemented have gone through till the present condition. Giuseppe Damiani Almeyda (1834–1911) can be seen as a paradigmatic figure of that particular historical moment in which the transition from the ancient art of building to the modern strength of materials occurred.

Maria Luisa Tuscano (Italy) introduced Antonio Maria Jaci (1739–1815), mathematics teacher of Messina. Tuscano's goal was to carry out a critical analysis of Jaci's scientific work which would be based also on newly discovered documents, currently under study in collaboration with the astronomical Observatory of Palermo.

Epaminondas Vampoulis (Greece) was supposed to speech of G*alileo's use of Practical Knowledge*; but some days before he passed. Kindly we report his abstract and a friendly remembership by Dimitra Giannara.

Valentina Zaffino (Vatican City State) inquired Giordano Bruno's great interest in the proportional eight spikes compass, invented (1567) by the Italian mathematician Fabrizo Mordente in order to measure the infinitesimal fractions of the angular degrees and to calculate the proportions between the lines, geometric shapes and solids.

Emanuele Zamperini (Italy) showed how modern structural engineering has been applied to a field of construction before ruled by empiricism and static intuition: timber trusses. He analyzed the situation from the 1860s and the 1870s, when first unsatisfying structural analysis methods were developed, to the early 20th century, when the production of new steel elements for timber connection allowed the use of the theory of statically-determinate trusses.[4]

Lille–Roma–Plzeň, July 2013
*The Editors*

[4] Others scholars only presented talks at SISFA 2012 Congress.

# An Outline of History of Mechanism Design in Servicing Science

**Marco Ceccarelli**

**Abstract.** In the paper an outline of historic evolution of service aspects of *Mechanism Design* (hereafter MD) for Science developments is presented with general considerations but emblematic examples as viewed from practical technical viewpoints. In general MD has evolved from a merely practical service to Science activity to a Science activity with return achievements and today it is even itself an instrumental means and motivation for further Science developments.

Key words: Mechanism Design, Service tasks, History of Mechanism Design

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## 1 A Short Introduction

The link among technological achievements and Science discoveries is a subject of study not only for historical tracking but also for understanding future trends. In general, the tradition gives a prominence of Science discoveries over technological achievements as from cultural viewpoints, also because in the past Technique and Technology were considered just as a consequence of Science, whatever happened even with independent evolution. In Antiquity Technology was considered of minor significance with respect to Philosophy and Science, as pointed out for example in (Ceccarelli and De Paolis 2008).

Science education has been and is still considered the necessary background and stimulus for technological achievements. But it is also true as from evidence in historical interpretations that Science achievements have been possible when suitable Technology and technical knowledge were available with proper levels of theory and practice. This other perspective has motivated and indeed justified scholar interests of engineers and technicians in finding and studying the history of engineering not only for tracking engineering evolution and its effects on technology but even for investigating motivations of technological developments as due to or inducing Science achievements with the aim to understand future trends of innovation.

In general, previous studies have investigated the abovementioned connections between Science and Technology mainly from viewpoints that are based on philosophical aspects and education purposes as mainly from the community of History of Science in a considerable well known literature. Particular attention has been addressed in understanding motivations and cultural developments that stimulated or limited technological growths and corresponding limited considerations in society frames, as stressed for example in (Koyré 2000).

In this paper an alternative perspective is presented as due to the character of engineer of the author whose main activity is in design and experimenting mechanical systems and robots. The problem of understanding the link between Science and Technology is here attached by looking at a modern approach mainly from engineering viewpoints.

## 2 An Account of History of Mechanism Design

History of Society developments is strongly linked with the history of technical developments that indeed influenced also political events. An understanding of this view is discussed in a large literature even as depending from perspective viewpoints like from Politics, Science, Philosophy, Education, Technology, Literature, and so on. Here, a specific focus of attention is addressed by looking at the specific fields of Mechanism Science (MS) as part of Technology and Engineering that contributed to evolution of the Society. In particular, this perspective can give the following indication of events as linked to traditional historical periods. Over time the changes of needs and task requirements in Society and Technology have required continuous evolution of machines and their uses, with or without a rational technical awareness.

Mechanisms and machines have attracted attention since the beginning of Technology and they have been studied and designed with successful activity and specific results. But the Theory of Machines and Mechanisms (TMM) reached maturity as an independent discipline only in the 19–th century. Today we refer to TMM as MS (as shortly can be indicated MMS Mechanism and Machine Science) since a wider engineering area can be identified as related to the mechanism concept (Ceccarelli 2004).

The historical developments of mechanisms and machines can be divided into periods as function of specific technical developments, according to author's personal opinion, such as:

- Utensils in Prehistory
- Antiquity: 5$^{th}$ century BCE (Mechanos in Greek theater plays)
- Middle Ages: 275 CE (sack of the School of Alexandria)
- Early design of machines: 1420 CE (the book Zibaldone with designs by Filippo Brunelleschi)
- Early discipline of mechanisms: 1577 CE (the book Mechanicorum Liber by Guidobaldo del Monte)
- Early Kinematics of mechanisms: 1706 CE (the book Traitè des Roulettes by Philippe De La Hire)
- Beginning of TMM: 1794 CE (Foundation of Ecole Polytechnique)
- Golden Age of TMM: 1841 CE (the book Principles of Mechanism by Robert Willis)
- World War I Period: 1917 CE (the book Getriebelehre by Martin Grübler)

- Modern TMM: 1959 CE (the journal paper Synthesis of Mechanisms by means of a Programmable Digital Computer by Ferdinand Freudenstein and Gabor N. Sandor)
- MMS Age: 2000 CE (re–denomination of TMM to MMS by IFToMM)

The historical evolution to the current MMS can be briefly outlined by looking at developments that have occurred since the Renaissance period. Mechanisms and machines were used and designed as a means to achieve and improve solutions in various fields of human activity. Specific fields of mechanisms grew in results and awareness, and the first personalities were recognized as brilliant experts, like for example Francesco Di Giorgio Martini (1439–1501) and Leonardo da Vinci (1542–1519) amongst many others, even with a social reputation (Ceccarelli 2008). At the end of the Renaissance period, Mechanics of Machinery attracted a great attention also in the Academic world, starting from the first classes given by Galileo Galilei (1564–1642) in 1593–98 (Ceccarelli 2006). In the 18$^{th}$ century the designer figure evolved with a professional status and strong theoretical bases finalizing a process that in the Renaissance saw the activity of closed small communities of pupils/co–workers after *mastros* and 'maestros'. Academic activity increased basic knowledge for a rational design and operation of mechanisms. The first mathematization were attempted and fundamentals on mechanism kinematics were proposed by the pioneering investigators, who were specifically dedicated to mechanism issues, like for example Philippe De la Hire amongst many others. The successful practice of mechanisms was fundamental for developments during the Industrial Revolution when many practitioners and researchers implemented the evolving theoretical knowledge in practical applications and new powered machines. The 19$^{th}$ century can be considered the Golden Age of machines and its science TMM since relevant novelties were proposed both in theoretical and practical fields. Mechanisms formed the core elements of any machinery and any technological advance at that time. A community of professionals was identified and specific academic formation was established worldwide. TMM gained an important role in the development of Technology and Society and several personalities expressed the fecundity of the field with their activity. The first half of the 20$^{th}$ century saw the prominence of TMM in industrial engineering but with more and more integration with other technologies. A great evolution was experienced when with the advent of Electronics it was possible to handle contemporaneously several motors in multi–d.o.f. applications of mechanisms and to operate 3D tasks with spatial mechanisms. The increase of performance (not only in terms of speed) required more sophisticated and accurate calculations that became possible with the advent of Informatics (with computers and programming strategies).

Today, a modern machine is a combination of systems of different natures and this integration has led to the modern concept of Mechatronics, Fig.1. Thus, most of the recent advances in machinery are considered to be in fields other than MD. But Mechanism Design can still be recognized as a fundamental aspect for developing successful systems that operate in the mechanical world of human beings. Tasks and systems for human beings must generally have a mechanical nature and a careful Mechanism Design is still fundamental in obtaining systems that assist or substitute for human beings in their operations.

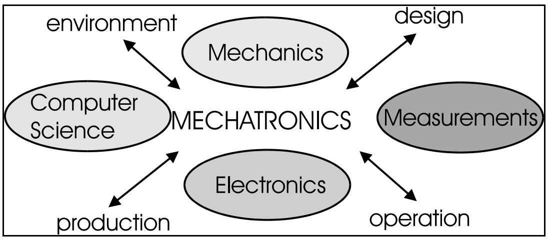


**Fig. 1** A scheme for the concept of Mechatronics

## 3 Considerations on Service Issues of MD for Science Developments

From historical viewpoint a summary can be pointed out with the following relationships:

- Science findings produced Technology advances.
- Technology developments stimulated Science discoveries.
- Science activities asked and produced Technological means.
- Science and Technology strongly interact simultaneously to advance or be advanced by each other.

In particular, a historical evolution of an engineering discipline can be recognized in phases like the above–mentioned ones that give for an initial accumulation of knowledge by technical experiences and observations, a science–dependent identity with prominence of theoretical and abstraction activities as supported by technical means, and at last an engineering activity in which Science and Technology are mixed to each other. Today many Science fields produce very valuable results both in knowledge and innovation because of the contemporaneous advancing in engineering expertises that are needed in their activities. This view is summarized in the scheme in Fig. 2 to stress main aspects linking Science to MD, as fundamental part of the corresponding Technology, and vice versa.

In Fig. 2 knowledge acquisition, implementation, and Science discovery can be considered the core of Science progress as helped or motivated by Technology advances. MD pay an important role in Technology when human–machine interactions and human–like actions are understood as fundamental for activities also in Science progress. This is because:

- Enhancements in knowledge and Technology needs for human life and industrial production have changed and evolved over time, also because of the evolution of systems, requiring innovation that have brought to Mechatronic design and operation of modern systems.
- Whatever Electronics, Informatics, Telecommunications and so on, will be enhanced and expanded in Mechatronics Technology, Mechanical Design will be always needed since a woman/man will always live and interact with the environment on the basis of mechanical phenomena of the human nature.

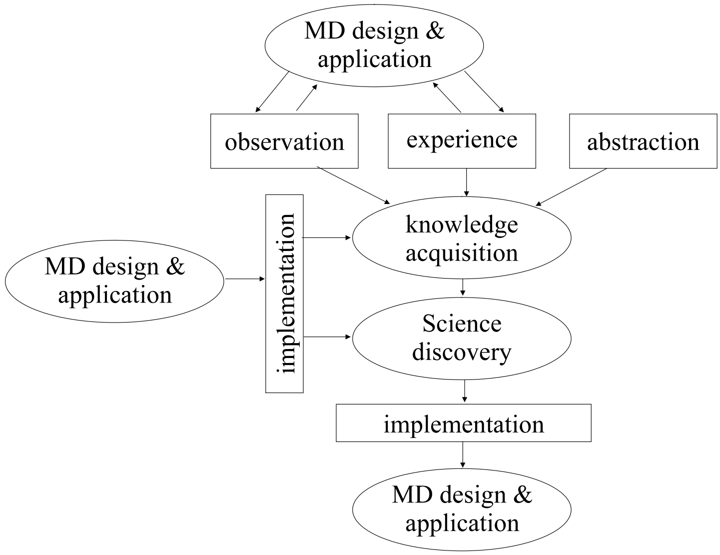


**Fig. 2** Simplified performance model for relationships among Science and MD activities

In particular, knowledge acquisition can be considered from engineering viewpoints as an aggregation of results from empirical activities, such as observations and experiments, and from abstraction with speculation and philosophical reasoning. Abstraction does not depend directly from empirical activities but it is usually stimulated by them. MD is directly involved in empirical activities as to provide the necessary means to perform experiences and observations at proper level of interactions and precision. Implementation activity refers to applications that need of real system with test or operation outputs. As indicated in Fig.2 MD can be of relevant role in Science progress not only as its servicing but even as receiving its results.

## 4 Examples of MD Servicing Science over the Time

In this section few examples are mentioned and discussed as cases of study on the above–mentioned considerations for the evolution of links between MD and Science towards the current mutual service.

In Antiquity Technology was not considered as a significant means for

Science but rather a practical consequence of it, although most of the times inventors and designers of machines had not any scientific formation or background. Nevertheless, there are also brilliant cases like Archimedes, who invented an d designed novel machines as an application of Science results, like for examples screw pump, odometer, torsion motor, (Chondros 2007; Ceccarelli 2010). But is also true that he used those machine inventions to prove the soundness of his studies.

In Renaissance, it is more evident how machines developments gave possibility of means that were useful for Science advances both for investigation and experimentation. A significant example can be the development of suitable mechanisms and machines for production of accurate glasses and mirrors, with proper curved shape, that were necessary for investigation in several fields such human anatomy and astronomy. For example Leonardo da Vinci studied mechanisms for manufacturing curved mirrors that he used for hi research activities in human anatomy. Even Galilei was used to prepare by himself the lens for his astronomy observations as well ass mechanism models for his experimental activity in mechanics. Other emblematic example is the study of rediscovered works of antiquity on machine design in which the understanding of the text required suitable expertise in machines, since those discoveries were with texts without figure. The work of the Roman engineer Vitruvius was discussed by several humanists with help of machine designers, who got inspiration from that also for new machine designs. During the Renaissance a long debate on Vitruvius machine design occurred involving scholars who became machine experts or needed expertise for such an interpretation study, such as Luca Pacioli, Fra' Giocondo, Daniele Barbaro, Federico Commandino just to cite few. The reconsideration of the work by Archimedes gave to Guidobaldo del Monte and Galilei also the possibility to analysis mechanics for machinery from scientific viewpoints.

During Industrial Revolution in 19$^{th}$ century there were cases by which Science produced advances in Technology and cases by which machine advances motivated Science discoveries.

As an example for the first cases, the development of electrical asynchronous motors was obtained by Carlo Ferraris as an application of his theory on magnetic fields. The second cases are emblematically represented by the evolution of steam engines that were initially developed as due Science fundamentals but then they were successfully evolved in power systems though applications by practical engineers. The extensive use of steam engines in Industry motivated investigations leading to the modern Thermodynamics and all the theoretical works that today are used to design and operate huge power production plants. The steam locomotives were developed first and then thermodynamics studies were worked out to obtain diagram to understand and improve their efficiency. In today modern research activities, Science and Technology are intimately linked to each other with continuous reciprocal demand and result of advances. Emblematic of this mutual service, that can be understood also in the proposed diagram in Fig. 2, can be considered the cases of research activities in biology and nuclear physics. In both cases investigations cannot be worked out without proper machines and innovative machines are produced by research results as well they are useful both for applications and advanced research plans.

Novel parallel manipulators are applied for handling accurately and fast samples of biological material to inspection instruments such us microscopes and other chemic analyzers. The precise manipulation of the samples is fundamental for a proper output of the biological and chemical investigations as well as the rapidity in exploring samples before their deterioration or transformation. Thus a fast precise machine is needed but even this kind of investigation is thought possible because of the existence of those machines with parallel manipulator architectures. Parallel manipulator machines were developed in late 1990s' after a long period of theoretical investigation by engineers and early applications were directed to industrial manufacturing and handling. Those experiences made them available also in other areas such as the afore mentioned biology research that nevertheless asked more advanced with respect to other aspects of machine operation, like high levels of cleanness and automatic operation with proper sensored control. Similar situation occurs in nuclear Physics where experiments at nuclear scale require precise and accurate force transmissions both for producing experiments and acquiring test results. Machines are available and machines are further improved for planned tests as based on the available machines. Indeed the modern practice of repeated experiments both for phenomena investigations and theory validations is obtained with automatic equipment that is very often based on robots and their mechatronic design. Robots were developed independently but still using Science results and nowadays they are often used as service means in Science laboratories for their high performance in manipulations task both in positioning and force transmission at any different scale that is possible thanks to proper mechanism designs. Not only machine designs are used in advanced Science research, but even their technical backgrounds and theories are useful in Science developments. An example is in the recent field of molecular design in which the molecule structures are manipulated by using the kinematic of motion that is applied for mechanism design. The molecules are treated as mechanisms and their topology is manipulated by using mechanism operation.

## 5 Conclusion

The service of MD (Mechanism Design) as mechanics–based part of Engineering, is illustrated in its historical phases of evolution form independent activities through a cultural dependency up to today mutual assistance towards enhancements in Science and Technology. The relevance of MD in servicing Science has been stressed as related to the mechanical nature of human–machine interactions that is a peculiar requisite in machine developments when dealing with mechanics based phenomena and/or operation, even within modern advanced Science research.

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# The Role Played by Mathematics during the Revolutionary and Imperial Paris up to the Restoration in the Education of Engineers with Lazare Carnot as a Witness

**Jean G. Dhombres**

**Abstract.** I am certainly sorry for too long a title. But as I wished without eliminating discrepancies to link debates that occurred during the revolutionary era concerning math teaching for engineers to changes in the mood of a society, I was sure to need some kind of literary fiction. I thus use a person, Lazare Carnot, as a witness to issues, which are so often neglected as being too technical to have an incidence on the social life. To counterbalance this somewhat subjective presentation, I present some original documents as their interpretation avoid long commentaries.

Key words: Algebraic analysis, Lazare Carnot, Descriptive geometry, Ecole polytechnique, Fundamental theorem of algebra, Laplace, Math curriculum for engineers

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## 1 The Issues I wish to Address

The interest in the historiography for the evolution of math teaching to engineers really begun by works about the French revolutionary decade: it was precisely the time when the Ecole polytechnique (hereafter *Ecole*) was founded (year III, or more precisely said from September 1794 onwards). By the title it obtained a year later, this school seemed to be devoted to all techniques in general. But was the sense of generality more or less what Auguste Comte (1798–1857) described in his *Cours de philosophie* positive, in 1830? At least was it far from any dominance of mathematics. This dominance is what the international common sense generally attributes to this school, and it was even considered as a cause for what was called the French scientific decline in the 1830's. Perhaps the reason is that it was also the time when the first "Cours de mathématiques"[1] appeared that devoted no room to applications to any kind of techniques: the Cours de mathématiques gave the impression just pure mathematics was necessary before investigating any kind of science or developing any engineering technique. This kind of imperialism is not what Comte later described as a "science de l'ingénieur" (Comte 2007) when he used Monge's *Descriptive geometry* as its paradigmatic domain. My first issue is to discuss what appears to be a contradiction. Can it be resolved by the difference for the work to be done at *Ecole* considered as a pioneering school for the industrial world, and the necessary study of mathematics for the preparation of its entrance exam? If the creation of this *Ecole* and of its development attracted a great deal of attention, as we have a very well documented text by Ambroise Fourcy (1778–1842; see Fourcy [1828] 1987), for which I was happy to prepare a critical edition on the occasion of the Bicentenary of the French Revolution (*Ibidem*), and archives are numerous, rather little was precisely said about what this *Ecole* modified in the general curriculum for Lycées and for what may be described as the first two years at the University. This concerns general education at the intermediate level, and for sure has to be studied in detail if one believes the Enlightenment idea pursued by revolutionary action, according to which scientific education was the main tool to modify the old society. Strangely enough, if the *Cours de mathématiques* in seven volumes by

[1] The first book named "Cours de mathématiques" only appeared in 1634, due to Pierre Hérigone (Dhombres 2013–*forthcoming*).

Sylvestre–François Lacroix (1765–1843), which was completely published by 1799, attracted some attention from historians of mathematics (Lamandé 2004; Domingues 2007) its lack of sections on mechanics, even on celestial mechanics, has not been emphasized as a proof of a professional turn in the corporation of professors of mathematics at the secondary level. This corporation was soon to be official with a law in 1802, which put Latin and Mathematics at the same equal level in the newly established Lycées. Was it not a signal for 19$^{th}$ century modernity and even the launching of a scientific humanism? Could it be exhibited in the specific classes that were organized in the Lycées to prepare students (all male) for the exam entrance to the *Ecole* then a civil school. This entrance oral examination was entirely focused on mathematics, with no physics or chemistry (even if they were to appear quite later in the 19$^{th}$ century), and no more mechanics than statics and elementary machines. Was it more or less in the description it used to get in the seventeenth century, or even back to Aristotle's *Mechanica* (lever, pulleys, etc)? In fact, composition of forces was at its basis, but with no specific choice towards a geometrical aspect or an analytical one. It was certainly not the form Lazare Carnot (1753–1823) had proposed in his *Essai sur les machines en general* (1783) or with his *Principes fondamentaux de l'équilibre et du mouvement*, which came twenty years later (Grattan–Guinness 1990; Dhombres and Dhombres 1997) with the use of the scalar product (without this terminology). So that even if one may consider that Carnot was a strong supporter of the *Ecole*, having had a great political power, he certainly had not been able to impose his personal views. The bulk of Lacroix' textbooks was officially what a student was supposed to know at the exam level; but Carnot did not send in 1800 his influential letter on new views about trigonometry to Lacroix, but to Bossut (See Fig. 7). Bossut was then an old man, who had begun publishing textbooks in the 1760's, never forgetting mechanics. Should it possibly be that things were to seriously change at the *Ecole*, after the preparation for the exam entrance with mathematics only? Was not mathematical physics the real aim? As we will have to see, the answer has to be negative, precisely because of the choice made for the generality being taught through mathematics at the *Ecole* after 1800.

A second but related issue could be to discuss the technocratic way the *Ecole* may have defined for the organisation of the State, as is the thesis defended by Bruno Belhoste (Belhoste 2003). By what was provided at the *Ecole* to exercise both future engineers and future scientists, I will here more specifically look for what might have helped to fashion meritocracy.

It may be considered as a part of the technocratic ideology, but in fact as I'll show, it is both a social and an epistemological conception. If mathematics was used as the only objective way to select an elite, which mathematics were then implied to justify this selection? Was the selection a pure question of cleverness, or was it mainly a question of adaptation to new modern times? Was it thought as a way to develop among engineers a sense of general interest and so to avoid the maintenance of a group with privileges like aristocrats of the Old regime? To answer, I chose to focus on the reactions of Lazare Carnot, a scientist and a politician for whom there too exists a huge literature. He was not a major actor, in spite of glorious political and scientific titles, but may be used as a convenient witness, notably that there was not one point of view only.

## 2 The Testimony of Carnot concerning the Preparation at the Ecole Polytechnique

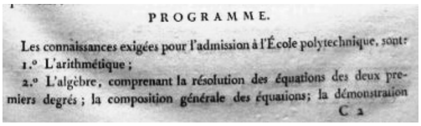
Proving meritocracy was favorized, the years of preparation to *Ecole* were important for Carnot himself and Carnot's family. This can be deduced from the not so well known portraits drawn by the same painter, Louis–Léopold Boilly (1761–1845) (See Fig. 1).


**Fig. 1** Lazare Carnot and his two sons around 1813[2]

[2] His youngest son is clad as a student preparing the Ecole polytechnique at a private institution, and the other already as a polytechnicien (Dhombres 2012). The father wears the uniform of a general, after having been for a short while Defense minister to Napoléon's regime. We should never forget that Carnot was one of the very few to refuse voting for the establishment of the Empire, and the only one from the military world to do so.

This painter, who has had his revolutionary mood, became specialized in bourgeois scenes gently representing the new ruling class which was to accept Napoléon because he stabilised revolutionary social conquests as well as organized functions of the State. But this class accepted less and less his wars, and the price to be paid in terms of men to serve in the army. Bourgeois class was certainly in phase with the Restoration to succeed the Empire, and found its acme in the July Monarchy. In spite of its Jacobin origin, the maintenance of the *Ecole* through such regimes, corresponds to an acceptance of this school by the ruling bourgeoisie, and the gentry as well, at least as a mean to get positions for their sons. But not perhaps from the higher merchants class, like in Nantes or Bordeaux). It was also a way to build a new generation of scientists. Carnot was not the only scientist of this period who wished his sons to follow the curriculum of *Ecole*, and the same was true for the chemist Berthollet, or for the mathematician Laplace. Lazare Carnot, son of a provincial bourgeois family from Nolay in Burgundy in search of better success, notably in Paris, took early the decision to help his two sons preparing the entrance exam to *Ecole*.

Sadi Carnot (1796–1832) succeeded, but Hippolyte Carnot (1801–1888) could not be examined, as he went into exile to Marburg with his father in 1815. To understand the requisites to the exam entrance on which Carnot worked as a parent, it is sufficient to read strong remarks about math teaching made at the turn of the century (See Fig. 2).



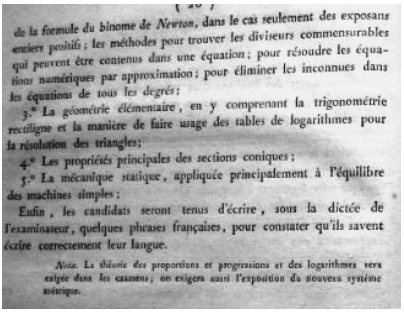
PROGRAMME.

Les connaissances exigées pour l'admission à l'École polytechnique, sont:

1.° L'arithmétique ;

2.° L'algèbre, comprenant la résolution des équations des deux premiers degrés ; la composition générale des équations; la démonstration

C 2



de la formule du binome de *Newton*, dans le cas seulement des exposans entiers positifs ; les méthodes pour trouver les diviseurs commensurables qui peuvent être contenus dans une équation ; pour résoudre les équations numériques par approximation ; pour éliminer les inconnues dans les équations de tous les degrés ;

3.° La géométrie élémentaire, en y comprenant la trigonométrie rectiligne et la manière de faire usage des tables de logarithmes pour la résolution des triangles;

4.° Les propriétés principales des sections coniques ;

5.° La mécanique statique, appliquée principalement à l'équilibre des machines simples :

Enfin, les candidats seront tenus d'écrire, sous la dictée de l'examinateur, quelques phrases françaises, pour constater qu'ils savent écrire correctement leur langue.

*Nota.* La théorie des proportions et progressions et des logarithmes sera exigée dans les examens; on exigera aussi l'exposition du nouveau système métrique.

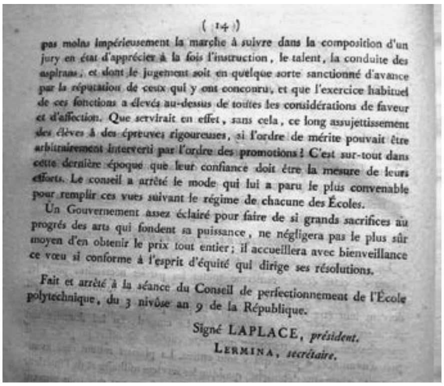
**Fig. 2** Themes at the Ecole Polytechnique[3]

[3] Source: see footnote 5.

The themes[4] were supposed to be known by candidates for the oral examination to enter *Ecole*, according to a report signed by Laplace in 1801.

## 3 The "Reform" of 1799 at the Ecole Polytechnique

With Laplace's name just met, we encounter the man who in many respects changed the *Ecole*, both its preparation as well as its curriculum, or better said found the way to intellectually and administratively organize the school within the somewhat older system of bodies of engineers, both civil and military. The first report of this council was effectively signed by Laplace in 1801 (See Fig. 3), once he had been ejected from his ministerial position, but began a career in the Senate of which he became archichancelier.



( 14 )

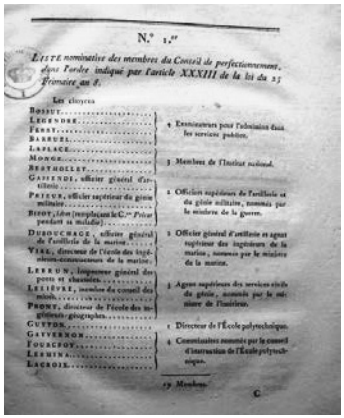
pas moins impérieusement la marche à suivre dans la composition d'un jury en état d'apprécier à la fois l'instruction, le talent, la conduite des aspirans, et dont le jugement soit en quelque sorte sanctionné d'avance par la réputation de ceux qui y ont concouru, et que l'exercice habituel de ces fonctions a élevés au-dessus de toutes les considérations de faveur et d'affection. Que servirait en effet, sans cela, ce long assujettissement des élèves à des épreuves rigoureuses, si l'ordre de mérite pouvait être arbitrairement interverti par l'ordre des promotions! C'est sur-tout dans cette dernière époque que leur confiance doit être la mesure de leurs efforts. Le conseil a arrêté le mode qui lui a paru le plus convenable pour remplir ces vues suivant le régime de chacune des Écoles.

Un Gouvernement assez éclairé pour faire de si grands sacrifices au progrès des arts qui fondent sa puissance, ne négligera pas le plus sûr moyen d'en obtenir le prix tout entier; il accueillera avec bienveillance ce vœu si conforme à l'esprit d'équité qui dirige ses résolutions.

Fait et arrêté à la séance du Conseil de perfectionnement de l'École polytechnique, du 3 nivôse an 9 de la République.

Signé LAPLACE, *président.*
LERMINA, *secrétaire.*

**Fig. 3** The signature of Laplace in 1801 on a report on the *Ecole*, indicating precisely what role this school was to play in the State[5]



N.° 1.er

*Liste nominative des membres du Conseil de perfectionnement, dans l'ordre indiqué par l'article XXXIII de la loi du 25 Frimaire an 8.*

Les citoyens

| | |
|---|---|
| Bossut, Legendre, Ferry, Barruel | 4 Examinateurs pour l'admission dans les services publics. |
| Laplace, Monge, Berthollet | 3 Membres de l'Institut national. |
| Gassendi, officier général d'artillerie; Prieur, officier supérieur du génie militaire; Biot, *Léon* (remplaçant le C.en *Prieur* pendant sa maladie) | 2 Officiers supérieurs de l'artillerie et du génie militaire, nommés par le ministre de la guerre. |
| Dubouchage, officier général de l'artillerie de la marine; Vial, directeur de l'école des ingénieurs-constructeurs de la marine | 2 Officier général d'artillerie et agent supérieur des ingénieurs de la marine, nommés par le ministre de la marine. |
| Lebrun, inspecteur général des ponts et chaussées; Lelièvre, membre du conseil des mines; Prony, directeur de l'école des ingénieurs-géographes | 3 Agens supérieurs des services civils du génie, nommés par le ministre de l'intérieur. |
| Guyton | 1 Directeur de l'École polytechnique. |
| Gayvernon, Fourcroy, Lermina, Lacroix | 4 Commissaires nommés par le conseil d'instruction de l'École polytechnique. |

19 Membres.

C

**Fig. 4** The composition of the *Conseil de perfectionnement* at the *Ecole*, with 19 members[6]

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[4] Mechanics appear though *machines simples*, which is an ambiguous terminology as it may as well mean geometry or analysis in the fundamental case of composition of forces; virtual velocities were excluded.

[5] A rigorous formation was justified by the ranking of students, and the possibility to have a second selection for offices, independent of any vocation

He had been made Home minister (*ministre de l'Intérieur*) just after Bonaparte's coup in Brumaire. Even if one assumes he did very little in general – who could work with so an hyperactive man as Napoléon? –, at least he managed a *Conseil de perfectionnement* for this school. The Council had to report about programs, and perhaps more important to find an equilibrium between what was taught at the Ecole polytechnique, and what was to come after, and waited by the various and rather conservative bodies of engineers. Thus *Ecole* was not the end of the professional formation as conceived in the first years, but a two years passage. It is precisely because of this passage that mathematics played a role. It is enough to show the list of names for the *Conseil de perfectionnement* to understand the kind of equilibrium that has been attempted to obtain. One immediately notices the importance of academicians (in fact members of the First class of the Institute) with Laplace, Monge and Berthollet. But names of Bossut and Legendre also appear, among the examiners for the entrance to military or civil schools to succeed *Ecole* and so were named Ecoles d'applications. A privilege had been recently established for the students at Polytechnique, with a direct access to these schools, depending on their rank at the *Ecole*. The generality at this school lies precisely in its intermediate position. With the importance given to what was to come after *Ecole*, there is something quite new in the organization of teaching, and in many respects not too far from what happens in councils for universities nowadays. Engineers, some civil like Prony or military like Dubouchage, were there to officially represent the various "corps". Notice also the name of the chemist Guyton de Morveau, who had been at the head of the *Comité de salut public* on its creation in April 1793. He belonged to the school of Lavoisier for the new nomenclature, and was in early 1800 director of the *Ecole*. Lazare Carnot had joined Robespierre in

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(*Rapport sur la situation de l'Ecole polytechnique présenté au Ministre de l'Intérieur* – Lucien Bonaparte – *par le Conseil de Perfectionnement établi en exécution de la Loi du 23 Frimaire an X*).

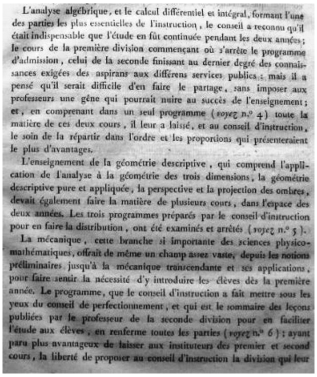
[6] They are not there for themselves, but as emissaries from different state "powers", the Institute representing the "power" of the scientists, and "corps techniques" being represented as well. Notice the absence of a member of the government, or of an administrator of the Home department. In fact, Lacroix had earlier exerted an administrative position. Source: see above footnote 5.

this Comité in August 1793. The name of Lacroix, at the time professor for analysis at the *Ecole*, shows as well the part played by the teaching body.

## 4 What the Place Given to Analyse Algébrique Indicates

I will not discuss in detail the program of all courses that this report provides, but will focus on the intervention of an expression: Analyse algébrique. It is its first appearance in a curriculum. The content, which is described in a specific section, prevents us to think this was just the pursuit of what Euler had mentioned as algebraic analysis, by which he meant the pursuit of Descartes' use of algebra, in particular for the study of curves (Dhombres 1992). Two main objects organized this new domain, which name to–day means nothing to us. One was to demonstrate that any equation of even degree is decomposable into real factors of degree 2 (Alvarez and Dhombres 2011; Dhombres and Alvarez 2012). This was precisely what Laplace had proved with originality and brevity in his courses at the Ecole normale in 1795. A consequence of this result, which is the reduction of imaginary quantities to the form $a+b\sqrt{-1}$ is also mentioned. But says the curriculum, it has to be proved by examples, such like the logarithmic function. So that the purpose of Analyse algébrique was not only to present polynomial algebra with complex numbers, but to explain as well the complex exponential function. If then Analyse algébrique was presented on an equal footing to Calculus, *and among the essential parts of instruction*, it means that this domain necessarily and intimately accompanies Calculus. In comparison, two years were found necessary to study the two linked domains. Lagrange had just retired as a professor of Analysis, and in fact his courses had already been optional. He had developed a theory of "analytic functions", with Taylor's expansion at its basis (but mainly in the real case) : this was not part of Analyse algébrique as described at *Ecole*. The "dictator", as Grattan–Guinness named Lagrange (Grattan–Guinness 1992) had in fact been ousted. Beyond Analyse algébrique, the main justification for the two years maintenance of a solid math teaching, was to develop at *Ecole* the way *Calculus* might be used in the professional écoles d'applications. But this teaching had to be without entering into specific technical domains, reserved to these schools in a rather corporative way. This was the second manner for justifying *generality* at *Ecole*, and a major decision concerning math teaching to future engineers. It brought academic freedom to professional practice. At this time, it was thought that applications might benefit from mathematics, in order to really change technical practice. This kind of preparation to Calculus, with such a strong influence of Laplace, is certainly not the way Carnot chose to explain what he called "une révolution aussi heureuse et aussi prompte que celle de l'analyse infinitésimale" (Carnot 1797, p 129). In his *Réflexions sur la métaphysique du calcul infinitésimal*, twice published in 1797, Carnot gave almost a physical, if not intuitive, value to infinitesimal calculus: he diminished the idea of computation.

> En décomposant, pour ainsi dire les corps jusques dans leurs élémens, elle semble en avoir indiqué la structure intérieure et l'organisation.[7]



L'analyse algébrique, et le calcul différentiel et intégral, formant l'une des parties les plus essentielles de l'instruction, le conseil a reconnu qu'il était indispensable que l'étude en fût continuée pendant les deux années; le cours de la première division commençant où s'arrête le programme d'admission, celui de la seconde finissant au dernier degré des connaissances exigées des aspirans aux différens services publics: mais il a pensé qu'il serait difficile d'en faire le partage, sans imposer aux professeurs une gêne qui pourrait nuire au succès de l'enseignement; et, en comprenant dans un seul programme (*voyez* n.º 4) toute la matière de ces deux cours, il leur a laissé, et au conseil d'instruction, le soin de la répartir dans l'ordre et les proportions qui présenteraient le plus d'avantages.

L'enseignement de la géométrie descriptive, qui comprend l'application de l'analyse à la géométrie des trois dimensions, la géométrie descriptive pure et appliquée, la perspective et la projection des ombres, devait également faire la matière de plusieurs cours, dans l'espace des deux années. Les trois programmes préparés par le conseil d'instruction pour en faire la distribution, ont été examinés et arrêtés (*voyez* n.º 5).

La mécanique, cette branche si importante des sciences physico-mathématiques, offrait de même un champ assez vaste, depuis les notions préliminaires jusqu'à la mécanique transcendante et ses applications, pour faire sentir la nécessité d'y introduire les élèves dès la première année. Le programme, que le conseil d'instruction a fait mettre sous les yeux du conseil de perfectionnement, et qui est le sommaire des leçons publiées par le professeur de la seconde division pour en faciliter l'étude aux élèves, en renferme toutes les parties (*voyez* n.º 6); ayant paru plus avantageux de laisser aux instituteurs des premier et second cours, la liberté de proposer au conseil d'instruction la division qui leur

**Fig. 5** The description of the main mathematical subjects to be taught at the Ecole polytechnique, showing the emphasis made on Algebraic analysis and integral and differential calculus[8]

This view on differentials was the maintenance in physics of what Jean and Daniel Bernoulli organized for instance in hydraulics in the 1730's, but it played a part as well to obtain the partial differential equation for heat propagation by Fourier in 1807. Such domains were not treated at the time at *Ecole*. Thus the meaning of the generality implied something Carnot did not understand in 1797 when he considered that

> L'analyse infinitésimale n'est autre chose qu'une application, ou si l'on veut, une extension de la méthode des indéterminées ; car suivant cette méthode, je dis que lorsqu'on néglige une quantité infiniment petite, on

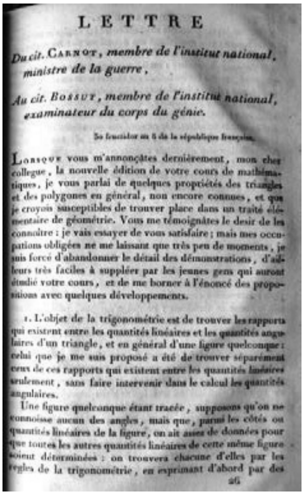
[7] Carnot 1797, p 129.
[8] Source: see above footnote 5.

> ne fait à proprement parler que la *sous–entendre* et non la supposer nulle.[9]

Complex exponential function requires more! The generality in Laplace's treatment of the fundamental theorem of algebra was to show how algebraic elimination theory normally led to complex numbers. And Analyse algébrique also indicated that pure algebra did not succeed in providing the complex exponential function, which was now essential to any use of mathematics in physics. However, a more serious change of mind could have been the harmonic oscillator as a model. To bring models was not the kind of ways of using mathematics recognized as valid. Nevertheless, the access to algebraic analysis was perceived as a way to adapt mathematical teaching to novelties, which were considered as essential for the future of science and of techniques as well. Even if the future was not clearly seen. The idea was that after such a formation, polytechniciens will form a group able to oblige écoles d'applications, and so bodies of engineers, to change their own methods, and give up the so often named "routine". The way mathematics was thought at *Ecole*, and for its preparation as well, was not a static one. It was seen in an evolutive way. That was made possible by the *Conseil de perfectionnement*. It did not succeed in the long term, but was enough for some few decades during the 19th century. In 1800, Carnot was unable to play any role for the *Ecole*: he was still in Germany, after his first exile in September 1797, and the Fructidor events. But two facts seem to show that Carnot was aware of the changes at *Ecole*. One thing is he wrote a letter to Bossut which was to be published in a new edition of the old *Cours* of this examiner, as already explained. In many respects Carnot's letter (See Fig. 6) organized what seem to have been the development of elementary geometry for the classroom, with analytical computations intervening directly. It seriously modified Euclid's *Elements*, which at the time Legendre was trying to recover in what he thought was their true origin. Recall Legendre tried also to prove the postulate for parallels! Carnot's letter contained geometrical problems, of the kind which will lead to Carnot's *Géométrie de position*, and which too will lead to the *Théorie des transversales*, one of the beautiful work of Lazare Carnot. This last theory will be used by math teachers in the Lycées. Thus, and even if I do not qualify the originality of

[9] Carnot 1797, § XXXVII, pp 163–164.

Carnot, here clearly was a distance taken with the position Carnot had had when he wrote his *Réflexions sur la métaphysique du calcul infinitésimal*.



LETTRE

*Du cit.* CARNOT, *membre de l'institut national, ministre de la guerre,*

*Au cit.* BOSSUT, *membre de l'institut national, examinateur du corps du génie.*

LORSQUE vous m'annonçâtes dernièrement, mon cher collegue, la nouvelle édition de votre cours de mathématiques, je vous parlai de quelques propriétés des triangles et des polygones en général, non encore connues, et que je croyois susceptibles de trouver place dans un traité élémentaire de géométrie. Vous me témoignâtes le desir de les connoître : je vais essayer de vous satisfaire ; mais mes occupations obligées ne me laissant que très peu de moments, je suis forcé d'abandonner le détail des démonstrations, d'ailleurs très faciles à suppléer par les jeunes gens qui auront étudié votre cours, et de me borner à l'énoncé des propositions avec quelques développements.

1. L'objet de la trigonométrie est de trouver les rapports qui existent entre les quantités linéaires et les quantités angulaires d'un triangle, et en général d'une figure quelconque : celui que je me suis proposé a été de trouver séparément ceux de ces rapports qui existent entre les quantités linéaires seulement, sans faire intervenir dans le calcul les quantités angulaires.

Une figure quelconque étant tracée, supposons qu'on ne connoisse aucun des angles, mais que, parmi les côtés ou quantités linéaires de la figure, on ait assez de données pour que toutes les autres quantités linéaires de cette même figure soient déterminées : on trouvera chacune d'elles par les regles de la trigonométrie, en exprimant d'abord par des

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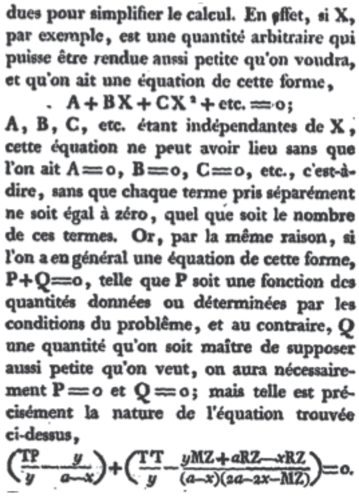
**Fig. 6** A letter by Lazare Carnot to appear in the Bossut's *Cours de mathématiques* in 1800[10]



dues pour simplifier le calcul. En effet, si X, par exemple, est une quantité arbitraire qui puisse être rendue aussi petite qu'on voudra, et qu'on ait une équation de cette forme,

$$A + BX + CX^2 + \text{etc.} = 0;$$

A, B, C, etc. étant indépendantes de X, cette équation ne peut avoir lieu sans que l'on ait A=o, B=o, C=o, etc., c'est-à-dire, sans que chaque terme pris séparément ne soit égal à zéro, quel que soit le nombre de ces termes. Or, par la même raison, si l'on a en général une équation de cette forme, P+Q=o, telle que P soit une fonction des quantités données ou déterminées par les conditions du problême, et au contraire, Q une quantité qu'on soit maître de supposer aussi petite qu'on veut, on aura nécessairement P=o et Q=o; mais telle est précisément la nature de l'équation trouvée ci-dessus,

$$\left(\frac{TP}{y} - \frac{y}{a-x}\right) + \left(\frac{TT}{y} - \frac{yMZ + aRZ - xRZ}{(a-x)(2a-2x-MZ)}\right) = 0.$$

**Fig. 7** Commentary by Lazare Carnot in his *Réflexions sur la métaphysique du calcul infinitesimal* in 1797[11]

Because of his insistence to mention his own proof, one may claim that Laplace was dominating the school. But one shall better appreciate that he was including in the program all what was necessary, and nothing more, from the theory of elimination worked by Cramer, and Bézout in the 18th century. This reduction is typical of some great moment in math teaching. In particular, Laplace made use of the famous result by Lagrange on the symmetric polynomials in *n* variables, which can be expressed by polynomials in the *n* elementary symmetric functions. And there is also the theory of development of rational fractions, which thus can be used easily for integral calculus. Claiming that the mathematical result had no impact on engineering methods of the time, is to forget the idea that such methodes were to change. Thus, what Laplace did, could prepare the path

[10] Source: see above footnote 5.

[11] The computation at the end of this text is just to show how to compute a tangent to a parabola, and one notices the algebraic setting. *Ibidem*.

for Cauchy, who acted exactly the same way to present *Calculus* at *Ecole*. Recall that Cauchy will precisely use the wording “Analyse algébrique”, for his famous course in 1821, the matrix of all other courses of Analysis. Except that Cauchy had what Laplace never tried to have, that is a sound basis for Analysis: definition of continuity, and the possibility to go to limits for (uniform) continuity with power series. Analysis could be pursued *per se*. In fact it is this tendency which will be named the *School of Laplace* around 1829, at the moment of the creation of the rival Ecole centrale des arts et manufactures. By opposition, the terminology was to revitalize what was called the *School of Monge*. The second domain in the 1801 report duly described *Géométrie descriptive*, obviously dear to Monge. But with the mention that it had a theoretical part as well as an applied one. It also contained applications of analysis to geometry, which in fact is more than analytic geometry (the name coined for Descartes’ and Fermat’ creation was recent), leading to differential geometry (curvatures). It was then a parallel course, not an optional one, analytical as well. Teaching was not unilateral at *Ecole*.

## 5 The Role of Textbooks

Laplace’s proof for the fundamental theorem of algebra appeared in the lessons given at the Ecole normale, on the day dated 11 germinal. This proof was reproduced by many authors, and in particular by Lacroix, in the second volume for algebra of his *Cours de mathématiques* in 1799. The fact that there is a second volume is important for the habits of working in French mathematical classes, a sort of anthropological habitus[12]. The same professor is reading to the students at two levels: and only those who feel fit are going to the second level. Most of the students choose the first year to read the first level only, and so the length of preparation to the entrance at *Ecole* tend to become two years. This already was the tendency when Lazare Carnot prepared the Ecole royale du génie de Mézières. He failed for the first exam in front of Bossut. I am sure that he thus considered that mathematics required a certain maturity. And this corresponded quite well to the later two years required for mathematics, this time at the *Ecole*. This

[12] Notice that here “instruction” in the 1801 report, does not restrict to mathematics, but to the whole study at Ecole polytechnique.

aspect, generally unnoticed by historians, is important to show that there was more in the teaching of mathematics than just a technique used for its role in engineering science. Whether we call it an ideology or an epistemological stance, it is clear that it gives a special turn to the technocratic ideology.

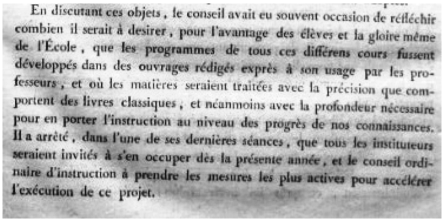

En discutant ces objets, le conseil avait eu souvent occasion de réfléchir combien il serait à desirer, pour l'avantage des élèves et la gloire même de l'École, que les programmes de tous ces différens cours fussent développés dans des ouvrages rédigés exprès à son usage par les professeurs, et où les matières seraient traitées avec la précision que comportent des livres classiques, et néanmoins avec la profondeur nécessaire pour en porter l'instruction au niveau des progrès de nos connaissances. Il a arrêté, dans l'une de ses dernières séances, que tous les instituteurs seraient invités à s'en occuper dès la présente année, et le conseil ordinaire d'instruction à prendre les mesures les plus actives pour accélérer l'exécution de ce projet.

**Fig. 8** The stress on textbooks to be written by professors[13]

**Fig. 9** A portrait of Fourier lecturing in mathematics in 1797[14]

Was the technocratic movement more visible in the third domain, mechanics, for the mathematical sciences the 1801 report was discussing? Was it seen as a part of "physico–mathematical sciences", the way Carnot imagined? No, and the "transcendental part", which means the use of integral calculus, and the theorem of virtual velocities, in the Lagrange manner of *Mécanique analytique* (first published in 1788), was not used.

## 6 Conclusion

To the first question I asked at the beginning, concerning possible epistemological reasons to ensure meritocracy though mathematics, by choosing algebra better than geometry, or analysis versus synthesis, I answer now by referring to the "revolutionary method". It was to claim new theories were to be taught. In the sense that they made students participate to research,

[13] Source: see above footnote 5.
[14] *Ibidem*.

to the point of showing enthusiasm. But an auxiliary demand was that these new methods should accelerate the process of understanding. In spite of its novelty, Lagrange's lengthy presentation of "analytic functions" was not accepted as it apparently brought nothing new in practice.

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# Some Methodological Remarks on the Replication Method

**Peter Heering**

**Abstract.** In the last decades, historians of science have developed a substantial interest in experiments and their role in creating scientific knowledge. Among the relevant aspects that came into the focus of the analysis were skills and performative aspects involved in scientific experimentation. This led to some methodological problems, as the respective traces are difficult to find in classical sources. One methodological approach that addresses these aspects is the replication method, which is not limited to redoing historical experiments, but also includes the reconstruction of the historical apparatus as well as the contextualisation of the experiences made during this process.

Key words: Replication method, Historical experimental practices, Solar microscope, Marat, $18^{th}$ century experimental practices

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## 1 Introduction: the Replication Method

Even though the Oldenburg group led by Falk Rieß did not create the replication method, it certainly has played an important role in developing and establishing this methodological approach in the period between the early 1980ies and the beginning of this century. In this period of almost 30 years, the members of the group undertook many case studies.[1] The intention of these studies was to analyse the practice in historical experiments, this could include material aspects of the related instruments and the experimental environment as well as practical and performative aspects of the manipulation of the instruments.[2] The aim of this method is not to check historical accounts of experimental findings, but to develop an understanding of the manner in which the historical actors may have achieved their experimental results. In this respect, it could be interesting to understand what kind of conditions may have been crucial to a certain experiment, and how the particular historical actor could have met them.
From an analytical point of view, the replication method can be described in three steps:

- Reconstructing of the historical apparatus
- Redoing of the experiment
- Contextualizing the experiences

Reconstructing the apparatus addresses the necessity to have an instrument that can be used during the process of analysing the practice. Consequently, it is necessary to create the instrument according to the information that has been gathered from the sources. Sources can be published accounts of the experiment, but also lab notes or letters. Moreover, there are also several examples where material sources were important in the process of gathering the information to reconstruct the apparatus. Even though the product of this step should correspond as

[1] A discussion of the development of the replication method and relevant publications not only from the Oldenburg group can be found in Heering and Höttecke 2013.

[2] It has to be added that most of the reconstructions had also an educational interest; the experiences made in analyzing these experiments were intended to be implemented in the education program that formed the background of the group.

closely as possible to the source information, the devices were normally not constructed with historical techniques, but modern machinery has been employed. Yet, there are also few examples where original historical instruments have been employed (see the next chapter of this contribution).[3] As the analysis is mainly focusing on the performance with the apparatus, it is not that important for the analysis how the instrument actually has been made – there are of course exceptions. On the other hand, as the analysis is aiming at developing an understanding of the historical practice with the apparatus, it is not sufficient to use a materialisation of the working principle of the apparatus. Instead, one has to aim at creating a device that corresponds as close as possible to the available information. Practicing with the instrument can on the first look compared with the practice of the historical actor, and it should be – like with the instrument – as close to the information as possible. However, there is one fundamental difference, and this is a basis of the methodology: The practice in the process of the replication method is self–reflexive. This means that the experimenter is trying to understand the development of her or his performative interaction with the apparatus as well as the skills that are developed in the process of experimenting with the apparatus. In this respect, the historian who is employing the replication method differs from the scientist who carries out an experiment. The contextualisation of the experiences made in the first two steps forms the third step of the analysis with the replication method. This means that the findings from the process of reconstructing the apparatus and redoing the experiment are related to the source information. In this respect, three aspects appear to be important in discussing the replication method on a more general level.

Evidently, the experiences made in the first two steps are not relevant by themselves, they do not have the status information from the sources have. It is necessary to connect these experiences to the sources, thus either tracing references in the sources that form a correspondence (and then it is this source information that becomes relevant for the historical analysis). Or, the experiences result in new questions which even may make it

[3] However, when an original device can be employed, is has to be understood that the instrument is not necessarily in the condition it had been when it was used originally. The device may have been altered by the historical actor in order to be used in another experiment, materials may have aged, etc. For an elaboration of this argument see Sichau 2002.

necessary to identify new materials as sources that had not been in the focus initially.

Secondly, these experiences can result in developing different readings of the initial sources. Frequently, some information that appears to be *hidden* in the text becomes more relevant after the process of experimenting. This is not to say that the sources have changed, but the perspective of the historian towards the sources becomes modified during the process of reconstructing the apparatus and redoing the experiment. Thus, in this respect the replication method can be seen both as a means to develop new perspectives and new readings of the source material.

Finally, it has to be stressed once again that these three steps are not clearly separated but closely interwoven: Even before beginning to build the apparatus, contextualisation takes place in order to identify additional sources that may contain information which are relevant for either making the apparatus or performing the experiment. Likewise, the process of reconstructing the apparatus cannot be fully separated from the redoing of the experiment – the necessity of some modifications may become evident only during the practice with the apparatus. Instead of discussing this methodological approach on a general and theoretical level any further, let me move to two case studies which will illustrate this procedure.

## 2 The Case Study on the Solar Microscope

Solar microscopes[4] are projection microscopes that were developed around 1740. The device used sunlight to project images of transparent specimens onto a wall or on a screen. For this purpose, the instrument was placed in the shutter of a window, the room was fully darkened, and the images appeared opposite to the instrument either in the wall (See Fig. 1*g*), or on a screen (See Fig. 1*c*).

[4] For a detailed discussion of my study on the solar microscope see Heering 2008, 2009. In this paper, I am using the case study as an illustration of some methodological aspects.

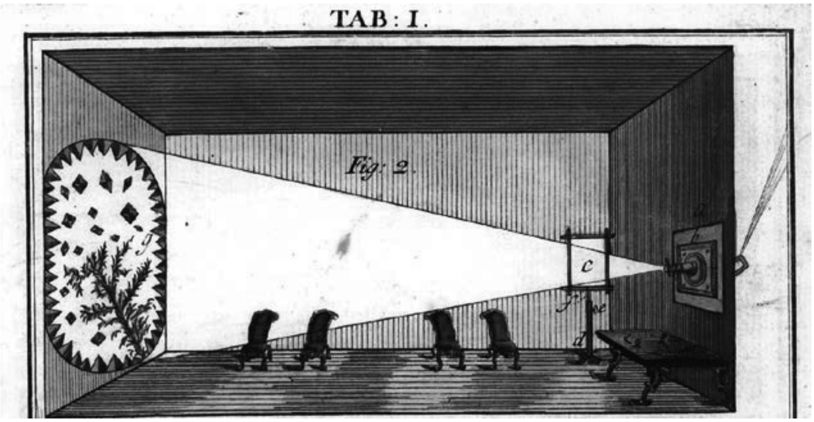


**Fig. 1** Working principle of a solar microscope[5]

The solar microscopes became extremely popular in the second half of the 18th century, and one may ask why. In order to give an answer, one may take a look at the historical reception of the instrument, and there appears to be a clue for the popularity of the instrument. To give but one example, let me cite a characterisation by Joseph Priestley, according to him

> […] the image or picture of the object is thrown distinctly and beautifully upon a screen of white paper, and may be magnified beyond the imagination of those who have not seen it.[6]

This is a rather typical characterisation of the potential that was ascribed to the solar microscope in the 18th century – particularly the phrase *beyond the imagination of those who have not seen it* can be found in several texts – and this poses a problem to the historian who is interested in analysing the practice with the instrument.

*How should such a historian deal with such a claim? How can one historicize experiences that are beyond the imagination of those who have not experienced them?* This example shows already that there are certain aspects in this sort of scientific practice where the classical methods in the historiography meet limitations and where the replication method could be a valuable tool to overcome these limitations.

5 Ledermüller 1762.
6 Priestley 1772, p 742.

However, in case of the solar microscope, things are somewhat more complicated, as the perception of the image created by the solar microscope is not constant. On the contrary, in the early 19th century, the perception changed:

> The image of a common solar microscope may be considered as a mere shadow, fit only to amuse women and children […]. The utmost it can do is to give us the shadow of a flea, or a louse as big as a goose or a jackass […]. The swinish vulgar will always be gratified by such spectacles, because they have no idea that a microscope of any kind is to do more than exhibit objects very much dilated in point of bulk.[7]

Evidently, there appears to be a contradiction between the perception of the 18th century natural philosopher Priestley and the 19th century microscopist Goring – but what does this tell us about the quality of the images and the practice with the device?

At the Deutsches Museum Munich, I had the opportunity to work with two original instruments, one made in the Dollond workshop, a device that could be taken as being a late 18th century state–of–the–art instrument. The other solar microscope was made by Junker and was supposed to be much cheaper than the English ones.[8] Both instruments were usable, for both, the original sliders still existed.[9] Even though both the optical quality of the instrument as well as the quality of the preparations differed, yet, it became evident that the projections with the solar microscope can be extremely impressive to an audience (Heering 2008; see also Cavicchi 2008).

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7 Goring 1827 quoted in Altick 1978, p 369.

8 It could be questioned whether this example is adequate in discussing the replication method, as no instrument was rebuilt. However, this is not a compulsory step. Furthermore, a solar microscope was also rebuilt in the entire project, even though I am not referring explicitly to the experiences with this devices, the analysis benefitted also from working with this instrument.

9 The instruments were cleaned in the restoration workshop of the Deutsches Museum, however, the preparations could only be cleaned on the outside of the sliders. Yet, there was substantial mould on the inside of several of the sliders; moreover, some of the preparations had decomposed. Besides using the original preparations, I also prepared new ones.

**Fig. 2** Projection with a solar microscope[10]

Thus, from looking at the images, one could argue that their quality corresponded more to the characterisation by Priestley and his contemporaries than to the one of Goring – however, things are not that simple. Moreover, I encountered the problem of how to communicate the observation: it turned out that Priestley's statement was addressing the problem very nicely, only that the problem was not the communication of the magnification but of the observational situation. The brightness of the image as well as the impression that the pictures made in the completely darkened room were hardly to communicate. Therefore, but particularly in order to reconstruct the historical situation which was very much aiming at creating a common observational situation, I started inviting guests into the darkened room. These guests were all extremely impressed by the atmosphere and the quality of the images, so at least I was in a situation where I could identify *honest witnesses* that would support my claims of

[10] Source: PH.

the quality of the images.[11] Moreover, it was tried to take pictures as well as well as to prepare a video, however, the products did not represent the quality and the impressiveness of the projections but are just unsatisfactory representations of what could have been experienced in the darkened room.

During the practice with the solar microscope, several other aspects became evident. On the one hand, I came to understand that the two instruments I used differed significantly in their user–friendliness (Heering 2009). From the practice with these two instruments, I was also able to use this understanding in analysing other instruments in this respect (Heering 2013). It also became evident that part of the fascination of the images arose from the observational situation. Thus, one could question whether this was relevant to the reception of the instrument. When trying to contextualize these experiences an interpretation of Jonathan Swift's Gulliver became extremely helpful. As Ulrich Stadler observed,

> [F]rom Gulliver's perspective, the world of Lilliput is a microscopic world, its inhabitants have – as it has to appear to the protagonist – microscopic eyes.[12]

Taking this as a starting point of the analysis of the observational practice with the solar microscope, differences towards the one with the classical microscopes became evident:

> What can be more pleasant and more appealing but when we – even without stepping out of our parlour – seemingly catch sight of a new world, or at least of completely new inhabitants, that were up to now entirely unknown to us? Our attention will be most excited when we encounter at an innumerable amount of midget animalcules in the smallest drop of water the same order, that we observe in the macroscopic and even in the entire cosmos?[13]

Two aspects in this description are relevant for the discussion. The microscope is placed in the same role as the telescope; it enables insights into a new world. Both instruments have in common that they enable the

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[11] For a discussion of the perception of these projections see Cavicchi 2008.
[12] Stadler 2003, p 94.
[13] Brander 1769, *Preface* [no pagination].

inhabitant of the macroscopic world to take a look into another world – this seems to be similar to Gulliver in Stadler's analysis. However, there is a distinction, and this distinction is created by the instrument: The instrument mediates between the observer and the world she or he is observing. Thus, the observer is not into the different world but just looking from the outside. This is different with the solar microscope, here, a particular room is created that is no longer part of the macroscopic world. This gets evident when clouds move between the sun and the mirror of the instrument. It gets dark immediately, but the persons in the room cannot tell what is going on outside of the room. They can wait for the light to come again, or they can open the shutter of the window, thus destroying the room. But as long as the room is illuminated, it is possible to encounter the inhabitants of the microcosm, and this possibility is at least in part responsible for the peculiarity of the observational situation with the solar microscope. This situation is implicitly, but at the same time in an exemplary manner, reflected by an account of the demonstrations with the solar microscope:

> To see this well–known small animal, I mean the flea, alive in the above mentioned size [of a lion or an elephant, P.H.] , arouses particularly for the fair sex no little pleasure. They laugh at his quaint shape, in which it appears. They point a finger at it, and, when they exclaim sarcasms against this miserable, they taste the sweetness of revenge for the mischief it did to them. Now they finally see how terrible their hereditary enemy is, whom they have known that long.[14]

What is remarkable in this quotation is the behaviour of the audience – they point a finger at the flea and exclaim sarcasms – in other words, they behave as if their hereditary enemy has been captured and is displayed to them. This perception of the flea being in the room with the observer is a symmetrical situation to Swift's Gulliver being in Lilliput. Thus, the analysis of the practice with the solar microscope reveals that the method creates a different understanding of the practice with the instrument. To summarize: it has become evident that the methodological approach can result in a broader understanding of the practice with, but also of the

[14] Anonymous 1781, p 460.

meaning of the instrument. At the same time, this case illustrates that it is insufficient to make the observation; it is the contextualisation that is relevant for the historical analysis. In the following, I will sketch some other case studies that exemplify other methodological aspects.

## 3 Jean Paul Marat's Experiments

Another example I would like to address is the analysis of the optical experiments of Jean Paul Marat. Marat, who is nowadays famous (or maybe infamous, depending on the perspective of the author) for his role during the French Revolution, tried to establish himself as a natural philosopher in the early 1780s. In doing so, he failed when he published a paper on optics that was intended to modify Newton's optical theory (Marat 1780a). The committee that was appointed by the Paris' Academy to examine his findings came to the conclusion that his experiments and his conclusions had to be rejected. There are of course many accounts where people report findings that were rejected by their contemporaries. Marat is in this respect of particular interest as – according to some historians – this rejection has been used to discredit him also as a politician:

> The traditional depiction of Marat's science as charlatanism or pseudoscience, however, has long served as a weapon wielded against the revolutionary phantom. If Marat's scientific thought was simple fraudulent, why should anything better be expected of his political ideology?[15]

A central device in Marat's experiments had been the so–called helioscope, a device that can be described as a solar microscope without the microscope. This instrument produces a light cone into a darkened room, and when an object is placed into the light cone, its shadow can be observed. Initially, Marat used the device to visualize (and manipulate) the matter of heat, the "fluide igné", as he called it (Marat 1780b, p 15). These experiments earned him some positive feedback from the Paris Academy. In his paper on optics, he placed solid objects into the light cone and

[15] Conner 1997, p 10.

described coloured frames at the shadows produced in this manner. Initially, this phenomenon was not clear to us. Moreover, the Academy's report indicated that this effect did not occur. Nevertheless, we reconstructed a helioscope based on a solar microscope that is kept at the Universiteitsmuseum Utrecht.[16] The initial experiments were a failure: of course, there were shadows, but no coloured frames. However, on a very bright day, it was possible to observe the effects described by Marat, and at the same time, it became understandable why the effects occur and why it had been so difficult to reproduce (not only for us, but also in the historical situation) the results Marat had described. The effects are not based – as Marat had claimed – on an attraction of light particles by matter. Instead, the effect can be explained with chromatic aberration. It became not only possible to reproduce several of Marat's experiments successfully. Taking this effect into consideration (which can be seen as an artefact of the instrument), it was also possible to give an appropriate explanation of these effects in terms of the modern theory. A crucial detail in order to produce the effect successfully was the atmospheric condition, it was essential to have a very clear blue sky. Few clouds (that would not at all affect the performance of the solar microscope) or even some high fog would prevent the observation of the aberration effects.

## 4 Conclusion

This paper aimed to give a theoretical outline of the replication method together with some examples. At this point, it has to be added that, contrary to what the case studies may indicate, the method is not limited to the analysis of experiments or instruments that were in the end rejected in the historical discourse. Of course, there are also several examples where the method had been employed in the analysis of canonical experiments (see e.g., Heering 1994, Sibum 1995, Nawrath 2010). The potential of this method lies in creating an access to the historiographical analysis of

[16] The original instrument was made available to us by Klaus Staubermann and Tiemen Cocquyt; the reconstruction was carried out with the technical assistance of Dipl.–Ing. Hans Holtorf. Most of the optical experiments were carried out by Sonja Woltzen. For a detailed analysis of Marat's experimental practice see Heering 2005.

practical and material aspects in the production of scientific knowledge. In this respect, it is clear that the method is not to be understood as being superior to other methods; it is just an additional approach that has to go together with the methods of classical historical research.

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# The Earth Floats Unsupported in Space

**Radim Kočandrle**

**Abstract.** According to Aristotle, Anaximander of Miletus explained the motionless position of the Earth in the universe by appealing to the principle of equilibrium. This study shows that such a conception would have represented a radical departure from the Ionian tradition, which tended to stress the role of air in supporting the Earth. Moreover, given the cosmological role of air, it is possible that this element played the same role also in Anaximander's thought. Aristotle's argument is in fact most likely based on Anaximander's notion of concentric circles of heavenly bodies around the Earth.

Key words: Anaximander, Aristotle, Cosmology, Equilibrium, Earth

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## 1 Introduction

It is generally recognised that Anaximander of Miletus who lived in the 6th century BCE, is one of the most prominent personalities of philosophy and beginnings of science in general. He wrote a book which was according to tradition one of the first works dealing with explanations of nature. We are not quite certain whether any authentic words from this work are indeed preserved but there is one sentence said to come from it and this sentence is often seen as the very first philosophical text in the Western tradition. And though this brief passage does not make it possible to draw conclusions about the book as a whole, based on references of later authors one can assume that Anaximander in his writing presented a conception of the origin of the world and of life itself. And among other things, he came up with a remarkable concept of cosmology. One of particular partial aspect of this concept will be the main focus of our study, namely Anaximander's explanation as to why the Earth remains motionless in its place at the centre of the universe. When Hippolytus (170–235 AD) reports on Anaximander's ideas pertaining to the place of the Earth in the cosmos, he says:

> The earth is suspended (μετέωρον), supported by nothing, staying there because it maintains equal distance from everything"[1].

This *being suspended* or *resting in mid–air* (μετέωρον) is also mentioned by Theon of Smyrna[2] (100 CE). Hippolytus presents a version of text which was related to him by Aristotle's (384–322 BC) disciple Theophrastus. And it was the explanation of the motionless position of Earth in the universe that was the reason why Aristotle himself explicitly refers to Anaximander in his treatise *De caelo*:

> Some say [the earth] stays in place [μένειν] by uniformity [διὰ τὴν ὁμοιότητά], as does Anaximander among the ancients. For it is no more fitting for what occupies the middle and is equally situated in relation to

[1] Hippolytus, *Refutatio omnium haeresium* (hereinafter *Refutatio*) I, 6, 3. See also Marcovich 1986, p 64; Diels–Kranz 2004–2005, 12A 11, p 84. Unless expressly stated otherwise, translations are taken from Graham 2010.

[2] *De utilitate mathematicae* 198, 18 in Diels–Kranz 2004–2005, 12 A 26, p. 88.

> the extremes to travel up than down or to the side; and it is impossible for it to make a move in contrary directions at the same time, so it stays in place by necessity[3].

The Earth thus remains in the middle thanks to equilibrium and *uniformity*. Aristotle explains the reason behind it in detail: it is impossible for something that is in the middle and at the same time *equally situated in relation to the extremes* to move to this or that side. Hippolytus' similarly structured report on 'equal distance from everything' also supports this reasoning. Hippolytus, however, does not explicitly mention that the Earth remains in the middle − he only speaks about it being freely suspended without being held by anything. But if Earth's distance is said to be 'equal from everything', its position in the middle can be implicitly assumed. And Aristotle writes in a similar vein when he notes that the Earth is in the middle only in the second sentence of his report. But how should we read the *πάντα*, which is mentioned when Hippolytus claims that the Earth remains in place because it is at *equal distance from everything* (*πάντων*)? At this point, Aristotle could perhaps again be of help since he speaks about the same distance from the *extremes*. But what sort of extremes does he mean? This text as a whole evokes an image of a circle or a sphere where the *πάντα* corresponds to all points at the perimeter. The expression then makes an impression of a geometric model and this is perhaps no coincidence since Anaximander's placement of the Earth is often explained against the background of geometry (Kahn 1960, p 54).

## 2 Symmetry

Anaximander's conception of Earth and heavenly bodies as well as their positions is infused with the idea of symmetry. As we shall see further on, symmetry is also reflected in the background of geometric expression of the universe related to us by doxography − though surprisingly enough, we do not have many reports about Anaximander's geometry. What we do have are in fact only reports about its concrete applications. And yet it is

[3] Aristotle, *De caelo* II, 13, 295b 10 in Diels–Kranz 2004–2005, 12A 26, p 81.

this subject that dominates the extant writings of Thales of Miletus. The only source which ascribes to Anaximander geometry in general is the *Suda* lexicon, according to which Anaximander "produced a general outline of geometry" (*Suda, s. v.* Ἀναξίμανδρος in Diels–Kranz 2004–2005, 12A 2, p 82). *Should we perhaps assume that the link between Anaximander and geometry was perceived as so obvious that only the particular examples, rather than geometrical principles were seen as worth mentioning? Or did Anaximander just apply geometrical principles without developing them further?* And yet, this was one of the most important parts of the legacy of the Miletian thinkers. Anaximander's explanation of the stability of Earth presupposes the use of a definition of circle. Still, it was Thales to whom Proclus ascribes the knowledge of dividing a circle by diameter in two equal parts (Proklos, *In primum Euclidis Elementorum librum commentarii* 157, 10 in Diels–Kranz 2004–2005, 11A 20, p 79). Based on such evidence, one could easily conclude that Anaximander adopted such and similar foundations of geometry from Thales.

The cosmological conception of Anaximander relies on geometric axioms which were at the same time applied to a general explanation of the principle of equilibrium. From these principles developed the particular explanation the stable position of the Earth, which is said to rests in the middle of the universe. If a body meets two basic conditions − namely, if it is in the middle and at equal distance from all edges, meaning all points at the perimeter − it must remain at rest. This explanation also uses the principle of sufficient reason: if there is no reason for a body to move in one direction rather than another, the body stays in place. Anaximander's argument is sometimes seen as the first evidence of use of the principle of sufficient reason, which was explicitly formulated by late pre–Socratics[4] Aristotle himself, however, criticises this principle in his treatise *De caelo* (Aristotle, *De caelo* II, 13, 295b 21 in Henderson 1939, pp 234–236), though it is not clear whether his objection was aimed at Anaximander's earlier explanation of the stability of the Earth in particular (Couprie 2011, pp 108–109).

[4] Aetius, *Placita philosophorum* (hereinafter *Placita*) I,25,4 in Diels–Kranz 2004–2005, 67B 2, pp 77–78.

## 3 The Conception of the Position of Earth in the Universe

It may look as if Anaximander's explanation presented a thorough departure from the view of Thales, according to whom the Earth was supposed to float on water, as Aristotle also records in his treatise *De caelo*:

> Some [say the earth] rests on water. This is the most ancient theory that has been handed down to us, which they say Thales of Miletus held: that it stayed where it was because it was buoyant like wood or something like that (for none of these things naturally stays in air, but on water) – as if the same problem did not arise for the water supporting the earth as for the earth itself![5]

Meanwhile, Aristotle himself notes that this is supposed to be the oldest extant explanation. He also does not hide that this is a hearsay report because the explanation he relates was rather just a part of tradition relating to Thales (leaving aside its possible Egyptian or Near–Eastern origin). If we understand Anaximander's conception as a thorough 'reworking' of the original notion, we should note that his explanation of the stability of the Earth was not generally accepted by his successors. Already Anaximenes is said to have explained the stability of Earth in a way similar to Thales, save for replacing in his conception water with air, on which flat Earth was supposed to float. This notion was recorded not only by Pseudo–Plutarch, who wrote:

> When air was felted he says the earth was formed first, being completely flat. Therefore it makes sense that it should float on air[6]

but also by Hippolytus:

> The earth is flat riding on air, likewise the sun and moon and the other heavenly bodies, which are all fiery, float on air because of their flatness.[7]

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[5] Aristotle, *De caelo* II,13,294a28 in Diels–Kranz 2004–2005, 11A 14, p 91.

[6] Pseudo–Plutarch, *Stromata 3* (hereinafter *Stromata*) in Diels–Kranz 2004–2005, 13A 6, p 91.

Both authors moreover note the importance of the flatness of the Earth. An analogical explanation was also supposed to have been presented by Anaxagoras and Democritus, who seem to have represented the then prevalent conception:

> Anaximenes, Anaxagoras, and Democritus say flatness is the cause of [the earth's] staying in place. It does not cut, but covers the air below like a lid, as we observe those bodies to do which have a flat shape; for these are difficult to move especially against the wind because of their resistance. Thus they say the earth owing to its flatness acts the same way in relation to the underlying air, which because it does not have any place to move, being contained by what is under it like water in a clepsydra, stays still.[8]

Here we again find a clear mention of the flat shape of the Earth, which is − together with the direct support by air − said to be the reason why the Earth remains motionless in the universe. Aristotle even expressed a view according to which thinkers who believed Earth to be flat thought that Earth's immobility necessarily implies such shape (Aristotle, *De caelo* II,13,294a8–19 in Henderson 1939, pp 222–224). One could thus very well wonder, whether it is possible that there indeed was a thinker between Thales and Anaximenes whose conception was radically different from these two philosophers (Heidel 1906, p 281; Robinson 1971, p 116). If we reject a continuity of thinking within the Ionian tradition, Anaximander's conception represents a model which may have soon been given up. Yet already in Plato's *Phaedo*, there appears a very similar explanation of earth's stability:

> I am convinced that, if the earth is spherical and dwells in the centre of the heavens, it needs neither the air nor any such force to keep it from falling, but the all–sided symmetry of the heavens [ὁμοιότητα τοῦ οὐρανοῦ] and the equilibrium [ἰσορροπίαν] of the earth itself are sufficient to hold it in its place. For whatever is in equilibrium and is set at the centre of a homogeneous [ὁμοίου] medium has no reason to

7 Hippolytus, *Refutatio* I,7,6 in Diels–Kranz 2004–2005, 13A 7. See also Marcovich 1986, pp 66–67.

8 Aristotle, *De caelo* II, 13, 294b 13–18 in Diels–Kranz 2004–2005, 13A 20, p 94.

> incline in one direction rather than another, but being neutral it will remain immobile.[9]

The emphasis on *all–sided symmetry of the heavens* together with the notion of a spherical Earth points to their similarity as to the shape. Within the whole presentation of the argument, however, it is mainly the equal distance of the centre from all points on the perimeter of the sphere that is, as far as symmetry is concerned, reminiscent of Anaximander. We could then consider the possibility that Anaximander's idea of explaining the stability of the Earth using symmetry was not entirely forgotten in the 5th century BCE. Though it is likely that none of his direct Ionian successors adopted Anaximander's conception, perhaps it did survive in the general awareness (Couprie 2011, pp 109–110; Kahn 1960, pp 78–80). In the writing of Aetius we find an almost identical explanation of Earth's stability which Aristotle ascribes to Anaximander, but this time it is Parmenides and Democritus who are credited with its authorship (Aetius, *Placita* III, 15, 7 in Diels–Kranz 2004–2005, 28A 44, p 225). In the case of Democritus, however, the report is clearly mistaken because this thinker believed Earth to be flat (Aetius, *Placita* III, 10, 5 in Diels–Kranz 2004–2005, 68A 94, p 106). Moreover, Aetius himself reports in the same text a different notion of the original state of the Earth, according to which the Earth stopped only after it thickened and became heavy (Aetius, *Placita* III, 13, 4 in Diels–Kranz 2004–2005, 68A 95, p 107). *Is not it thus possible that Aristotle was also mistaken in the case of Anaximander?* Possible perhaps but most scholars believe that Aristotle ascribes the entire argument to Anaximander correctly (Cornford 1965, p 165; Guthrie 1985, p 99; Kahn 1960, pp 77–78; Kirk–Raven–Schofield 2007, p 134; McKirahan 1994, p 40; Wright 1995, p 39). After all, textual evidence available to us strongly suggests such conclusion, especially given the fact that Aristotle, who hardly ever mentions Anaximander by name, does so in this very context.

[9] Plato, *Phaedo* 108e–109a. Couprie's translation (Couprie 2011, pp 109–110).

## 4 The Earth and the Universe

There are, however, some very important circumstances, which suggest that the argument presented above does not correspond to the key features of Anaximander's concept of the universe. To wit, while in Plato the entire notion is based on the identically spherical shape of the Earth and the universe, in Anaximander's case we know nothing about the shape of the universe but we are almost certain that he believed Earth to be flat. In his thinking, the Earth thus had the same shape as was believed by other Miletians.

Anaximander's conception of the universe is, of course, based on his description of the cosmogonic process, which is known to us only from Pseudo–Plutarch's report:

> He says that that part of the everlasting which is generative of hot and cold separated off at the coming to be of the world–order and from this a sort of sphere of flame grew around the air about the earth like bark around a tree. This subsequently broke off and was closed into individual circles to form the sun, the moon and the stars.[10]

Immediately preceding the text quoted just above, Pseudo–Plutarch also speaks of the shape of the Earth. It is described as a cylinder, whose size (which is unknown to us) is determined by particular proportions:

> He says the earth is cylindrical in shape, and has a depth one third its width.[11]

Earth's shape is described also by Hippolytus:

> Its shape is concave, round, like a column drum. We walk on one of its surface, and there is another surface opposite.[12].

The above mentioned comparison with a stone column is also used by Aetius (Aetius, *Placita* III, 10, 2 in Diels–Kranz 2004–2005, 12A 25, 12B,

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[10] Pseudo–Plutarch, *Stromata* 2 in Diels–Kranz 2004–2005, 12A 10, p 83.

[11] *Ibidem.*

[12] Hippolytus, *Refutatio* I, 6, 3 in Diels–Kranz 2004–2005, 12A 11, p 84. See also Marcovich 1986, p 64.

p 87). It seems, though, that what he means is not the entire column but rather just its part, a drum. We should thus imagine Earth as a sort of low, flat cylinder (Couprie 2011, pp 104–106). In Anaximander's view, while Earth was flat, heavenly bodies were supposed to be circular:

> The heavenly bodies came to be as circles of fire, separated from the cosmic fire, surrounded by air. There are certain tubelike [airy?] passages for breathing holes, through which the heavenly bodies appear. Accordingly, when the holes are blocked there are eclipses.[13]

In his view, heavenly bodies are the remains of the cosmogonic fiery sphere. When this sphere broke up, its fire created circles. These were subsequently surrounded by air–mist, which was originally enclosed in the sphere. And though the fire of a heavenly body is now covered by the air–mist, one can catch a glimpse of it through a vent hole. The Sun and the Moon, which appear to us as discs, are thus in fact only vents into the whole circle, vents through which shines the original fire. The nature of heavenly bodies is thus expressed using meteorology as well as geometry.
The whole universe then consists of concentric circles of heavenly bodies which rotate around the flat cylinder of the Earth in their middle, while the circles are placed one after another. Closest to Earth are the circles of the stars, which are followed by the circle of the Moon, and the circle of the Sun is furthest from the Earth. What we do not know is whether each star is represented by its own circle or is perhaps conceived of differently. One can, however, assume that their nature was analogical to the Sun and the Moon. In this context, it should be noted that doxography tends to focus mainly on the Sun and the Moon, while the issue of stars and planets was somewhat neglected. It is not clear, however, whether this is a consequence of poor preservation of textual evidence or whether it actually relates something about Anaximander's cosmology and its focus on the Sun and the Moon (Couprie 2011, pp 99–102).

Coming back to the issue of explanation of the motionless position of the Earth in the universe, we saw that in the argument based on the notion of equilibrium, the spherical shape of the Earth is supposed to correspond to the spherical shape of the universe. The problem is that Anaximander

[13] Hippolytus, *Refutatio* I,6,4 in Diels–Kranz 2004–2005, 12 A 11, p 9. See also Marcovich 1986, p 64.

believed Earth to be flat and we can only guess what shape he ascribed to the universe. Given that stars are supposed to be closest to the Earth, however, it is likely that Anaximander did not believe in the existence of a heavenly vault, which would partially represent a sphere in which the universe is enclosed. A sphere is mentioned in connection with cosmogony, where one can suspect that Earth may have been situated in the middle of the fiery sphere, but this sphere subsequently fell apart and formed the circles of heavenly bodies. *But in this case, is it not possible that Aristotle describes Anaximander's cosmogony?* And where the argument mentions the equal distance of Earth from everything, we could consider in this context the possibility that what is meant are the circles of the stars − at least assuming that they jointly form a sphere. Yet the Earth is rather clearly described as cylindrical and does not fit this image at all well. It thus seems that we have hit something of a dead end. Fortunately, there is one other text that could shed more light on this whole complex issue.

## 5 The Role of the Air

Simplicius in his commentary on Aristotle's *De caelo* notes that alongside symmetry, Anaximander explained the stability of the Earth also by the support of the air:

> Anaximander believed that the earth remains aloft because of the air supporting it, and also because of its equilibrium and uniformity [ἰσορροπίαν καὶ ὁμοιότητα].[14]

Simplicius here distinguishes two separate aspects of the explanation. The motionlessness of the Earth is given firstly by its suspension in the air and secondly, by equilibrium and uniformity. John Robinson notes that the issue of motionlessness of the Earth can in fact be divided in two partial issues. Firstly, one needs to explain why the Earth − given, among other things, its weight − does not move vertically, that is, why it does not ultimately fall but rather remains in place. This is where the assumption of

[14] *Aristotelis De caelo commentaria* 532, 13–14. Hahn's translation (Hahn 2010, p 54).

some sort of support comes into play. Secondly, one needs an explanation of why the Earth does not move horizontally in this or that direction (Robinson 1971, pp 116–117). Moreover, one could assume that the Earth rests on air already based on the cosmogony. We saw that during this process, the Earth was surrounded by air and after the break–up of the fiery sphere the air enveloped the fiery circles of heavenly bodies. In that case, the air must have filled the universe including the space under the Earth, which thus rested on it. In connection with the role of the air, one could consider another reason for the stability of the Earth. Aristotle namely claims that some thinkers explained the position of the Earth at the centre of the universe by a *vortex* (δίνη) (Aristotle, *De caelo* II, 13, 295a 8–15 in Henderson 1939, p 230). It was the assumption of a vortex, which convinced numerous scholars that Aristotle's presentation of Anaximander's argument regarding Earth's stability should be rejected (Furley 1987, pp 23–28; Heidel 1906, pp 279–282; Robinson 1971, pp 111–118). This would make Simplicius and his traditional explanation of Earth's stability supported by the assumption of a vortex much more important. On this conception, Earth's immobility could be a result of the cosmogonic process. The Earth would stay at the centre of the universe due to conditions arising in the course of cosmogony, whereby the fiery sphere represents the active and air the passive element (Bicknell 1966, p 42; Naddaf 2005, pp 74–75).

## 6 Conclusion

*Was Aristotle wrong when he ascribed Anaximander the argument described above?* The problem could naturally be present already in Anaximander's text, which may have been less than precise and consistent. In any case, it seems that Aristotle based his writing on some textual support which he may have misunderstood. If, following Robert Hahn, we take into account the drawing of the map of the world, which doxographers repeatedly ascribe to Anaximander, we could also consider the possibility that a map of the universe may have been executed in a similar way, that is, as a ground view. In such case, the argument about the stability of the Earth may have corresponded to a drawing of the universe from a ground view. In a cross section, the Earth would be positioned in the middle of concentric circles of heavenly bodies, and would therefore be in a stable, balanced position. This image, however, says nothing about Earth's vertical movement (Couprie 2011, p 111; Hahn 2001, pp 198–200, 2010, p 56, pp 64–74).

Though we cannot be certain, we could assume that if the cosmological conception in general counted with the placement of the Earth in the middle of circles of heavenly bodies, Aristotle's report may have been based on some such connection. At the same time, however, the whole explanation of the stability of the Earth was probably based on the fundamental role of the air, which not only surrounded the Earth but also served as its support. In any case, one can conclude that Anaximander's cosmological vision of the structure of the world is based on geometry, which represented all manner of cycles by circles. And it is possible that it was this regularity of cycles that inspired Anaximander's conception of the ordering of the world. The order of the universe is expressed by various mutual relations and proportions as well as by balance, stability (Kahn 1960, p 80, p 130; Naddaf 2005, p 75).

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# Physics and Mathematics without Coordinates

**Walter Noll**

**Abstract.** From Descartes until now, coordinates have played a useful and crucial role in combining the geometry as developed by the Greeks with the Analysis that began to be developed at the time. However, it is now obsolete to use coordinates when dealing with conceptual issues and more efficient to use more sophisticated mathematical tools. In the paper there is shown how to afford a mathematical physical problems without the use of coordinates.

Key words: Coordinates; lineons, Special relativity, General relativity, Continuum mechanics

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# 1 A Short Introduction

To get your attention, I will start with a quote from the most famous scientist of the first half of the 20th century:

> Why were another seven years required for the construction of the general theory of relativity. The main reason is the fact that it is not so easy to free oneself from the idea that coordinates must have an immediate metrical meaning.[1]

The following quote is from a far less famous scientist:

> The approach of this treatise is conceptual, geometric, and uncompromisingly coordinate–free. In some of the literature 'tensors' are still defined in terms of coordinates and their transformations. To me, this is like looking at shadows dancing on the wall rather than at reality itself.[2]

From Réne Descartes (1596–1650) until now, coordinates have played a useful and crucial role in combining the geometry as developed by the Greeks with the Analysis that began to be developed at the time. However, it is now obsolete to use coordinates when dealing with conceptual issues and more efficient to use more sophisticated mathematical tools. Of course, coordinates are still needed when dealing with specific practical situations. More often, it is most useful to employ not Cartesian coordinates but cylindrical, spherical, barycentric or other kinds of special coordinate–systems. The now well–known GPS system is a very sophisticated modification of a barycentric system.

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[1] He is of course, Albert Einstein (1879–1955) and the quote is cited in *Space–time with and without coordinates* (Misner, Thorne and Wheeler 1973, Section 1.2).

[2] It is a quote by a far less famous scientist, namely me (Walter Noll) in *Finite–Dimensional Spaces, Algebra, Geometry, and Analysis* [FDS] (Noll 1987, Introduction, Part F).

## 2 Continuum Mechanics

When I arrived as a graduate student at the Indiana University in 1953, most (perhaps all) research in continuum mechanics was using the infrastructure of *tensor analysis*, all with co–ordinates, upper and lower indices, etc. I wrote my thesis in the summer of 1954, with Clifford Ambrose Truesdell (1919–2000) as my thesis advisor. Much of it was written using a coordinate–free infrastructure. Not being used to this, Clifford forced me, on at least 14 occasions, to add coordinate versions of my equations. Later, Truesdell himself wrote coordinate–free papers.

In January 1958, I accepted an invitation from Truesdell to serve as a co–author of a treatise called *The Non–Linear Field Theories of Mechanics*, to be published as a part of the *Encyclopedia of Physics*. From now on, I will refer to this treatise by NLFT (Noll 1987). Over the years it became the standard reference for continuum mechanics. It was republished in 1992 and 2004. It was translate into Chinese in 2000. A paper of mine called *The Genesis of the Non–Linear Field Theories of Mechanics* can be found on my website[3].

I believe that Truesdell was a much better scholar than I, but I was a better thinker. Unfortunately, the mathematical foundations of Continuum mechanics given almost 50 years go in NLFT (Noll 1987) were deeply flawed. I will describe a modern and much better foundation later in this conference in the lecture with the title *Basic Concepts of Thermomechanics*.

## 3 Geometry

Almost all Geometry starts with a *flat space* (a.k.a. affine space).

Definition 1: *A* flat space *is a non–empty set E endowed with structure by the prescription of*:

i. *a commutative subgroup V of Perm E whose action is transitive.*
ii. *a mapping sm:R×V:→V which makes V a linear space when composition is taken as the m addition and sm as the scalar multiplication in V.*

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[3] via: http://www.math.cmu.edu/math/faculty/noll.html

The linear space $V$ is then called the translation space of $E$. Given $x, y \in E$, it can be proved that there is exactly one $v \in V$ such that $v(x)=y$, and we write $y-x:=v$ for this element of $V$. It is customary to use additive notation for $V$ and $E$:

$$v(x) := x + v, \quad u + v := u \circ v, \quad 0 := 1_{\varepsilon}, \quad -v = v^{\leftarrow} \tag{1}$$

valid for all $x, y \in E$; and all $u, v \in V$.

The conditions [i] and [ii] are illustrated by the following Fig. 1:

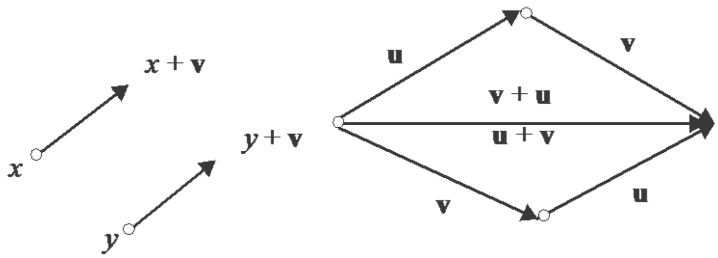


**Fig. 1** Composition of points and vectors

Flat spaces are not good enough to define distances and angles. It is necessary to consider the space $Sym_2(V^2)$ of symmetric bilinear mappings with values in $R$. With each such space $S \in Sym_2(V^2)$, one can associate a mapping $Q_S : V \rightarrow R$ defined by

$$Q_S(u) := S(u, u) \qquad \text{for all } u \in V \tag{2}$$

This mapping is injective and hence it can be made invertible by changing it codomain to its range without change of notation. It is then called the *quadratic form* associated with the *symmetric bilinear mapping*[4] *S*.

Definition 2: inner product spaces

*An inner–product space is a linear space V endowed with additional*

[4] Details can be found in Section 27 of FDS (Noll 1987).

*structure by the prescription of a symmetric bilinear mapping ip* $\in$ $Sym_2(V^2)$ *with the property that the corresponding quadratic form sq, as defined in accord with Eq. 2 is strictly positive in the sense that sq(u) is strictly positive for all strictly positive u* $\in V$.

It is customary to use the following simple notations:

$$v^{\bullet 2} = sq(v) \qquad \text{for all } v \in V \tag{3}$$
$$u \bullet v = ip(u, v) \qquad \text{for all } u, v \in V \tag{4}$$

The symmetry and bilinearity of ip is then translated into the following rules

$$u \bullet v = v \bullet u$$
$$w \bullet (u + v) = w \bullet u + w \bullet v$$
$$u \bullet (\xi v) = \xi (u \bullet v) = (\xi u) \bullet v$$

valid for all $u, v, w \in V$ and all $\xi \in R$.

The *magnitude* of a given vector **v** can now be defined by

$$|\mathrm{v}| := \sqrt{\mathrm{sq(v)}} = \sqrt{\mathrm{v}^{\bullet 2}}\ . \tag{5}$$

The *distance* between two points $x$ and $y$ in $E$ is given[5] by

$$dist(x, y) := |x - y| = |y - x| \tag{6}$$

## 4 Special Relativity

As in the case of Geometry, the description of the *Event–World* of Special Relativity starts with a flat space E, whose members are called events or *world–points*. The translation space of E is denoted by $V$, as in Definition 1 of Section 3 and its members are called bf world–vectors.

[5] Details can be found in Section 41 of FDS (Noll 1987).

Definition 3: non–genuine inner product spaces, or n.–g. inner product spaces for short

*An n–g.–product space is a linear space V endowed with additional structure by the prescription of a symmetric bilinear mapping* $rip \in Sym_2(V^2)$ *with the property that the corresponding quadratic form rsq, as defined in accord with (Eq. 2) is non–degenerate in the sense that*

$$rip(u,v) = 0 \qquad \text{for all } v \in V \text{ implies that } u = 0 \tag{7}$$

but that *rsq* is no longer strictly positive. We use notations as Equations 2 and 3 as in Section 3 except that *rqu* and rip is used instead of *qu* and *ip*, respectively. However, we can no longer define magnitude and distance because *rsq* is no longer strictly positive.

Let a subspace *U* of *V* be given, we say that *U* is positive–regular if $rsq|_U$ is strictly positive. We say that U is negative–regular if $-rsq|_U$ *is* strictly positive. We say that $rsq|_U$ is totally singular if $rsq|_U = 0$.

Definition 4: Signatures. Let an *n.–g.* inner product space *V* be given.

*The greatest among all dimensions of positive, negative, and totally singular subspaces of V are denoted by* $sig^+V$, $sig^-V$, *and indV, respectively. I believe that Special Relativity cannot be fully understood without knowledge of the following Signature Theorem.*

We have

$$sig^+V + sig^-V = dimV, \tag{8}$$
$$indV = min(sig^+V, sig^-V). \tag{9}$$

Let a subspace *U* of *V* be given. Then the following three conditions are equivalent[6]:

a) $dim(U) = sig^+V$.
b) *U is maximal among the positive–regular subspaces of V.*

[6] A proof of this theorem is in Sect. 47 of FDS (Noll 1987). The earliest proof of a version of it was given in 1852 by J. J. Sylvester.

c) *the set* $U^{\perp} := \{v \in V | \ v \bullet u = 0$ for all $u \in U\}$ *is a negative – regular subspace of V.*

In the case of Special Relativity, the space *E* of world–points and the space of world vectors is 4. The signature is Eq. 7. To choose a *space–time decomposition* means to choose a maximal positive–regular subspace *U* of *V*. The elements of the three–dimensional space *U* are called *space–like* and the elements of the one–dimensional space $U^{\perp}$ are called *time–like*. There are infinitely many such space–time decompositions.

A coordinate–free treatment of Special Relativity is given in the book *Mathematical Structures of Special Relativity* on my website[7]. It was written by Vincent Matsko and me and is. I based on hand–written lecture notes by me. Matsko is a former doctoral student of mine.

## 5 General Relativity

The three famous papers that Einstein published in 1905 required little knowledge of very sophisticated mathematics. When he tried to generalize special Relativity to include Gravitation he realized he had to learn what later became *tensor analysis*, which can become very complex but certainly is not coordinate–free. He frequently corresponded with David Hilbert, who, at the time, was the most influential mathematician in the world. In 1915 he succeeded and General Relativity was created and was extraordinarily successful.

In about 1970, at a conference in Germany, I was asked by a Physics professor whether General Relativity could be made coordinate–free. I said yes, but it took me decades to develop the necessary background. Now it can be found in Section 55 of the book *Geometry of Differentiable Manifolds* by me and my former doctoral student Sea–Mean Chiou (Noll and Sea–Mean Chiou 1994).

## 6 Conclusion. Lineons Versus Matrices

Let a linear space *V* of dimension *n* be given. Then the linear space *LinV* of

[7] via: http://www.math.cmu.edu/math/faculty/noll.html

all linear mappings from *V* to itself has dimension $n^2$. We call the members of this space *Lineons* for short. In the case when $V{:=}R^n$, $LinR^n$ can be identified with the $n^2$–dimensional space $R^{n\times n}$ all numerical square matrices. However, if V is not $R^n$, one can associate with a *lineon* L $\in$ *LinV* a square matrix only after a basis of *V* has been chosen. Since there are infinitely many such bases, we get infinitely many matrices, all associated with one and the same *lineon L.*

The concepts of *trace*, *determinant*, etc. do not belong to matrices, but to lineons. They all are mappings with domain *Lin V* and codomain *R*. The trace is linear, but, if $n>1$, the determinant *det* is not. It is what I call a *power mapping* of degree *n*. Both are analytic. I am in the process (Noll 1987, Vol. II) of deriving formulas for all the gradients of *det*. The $m^{th}$ gradient of *det* is zero when $m > n$.

Until now, the mathematical literature is full of matrices. Most should be put in the trash, or, at best, in a museum. They should be replaced by *lineons*, except in numerical analysis.

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# The Search for the Standard Model Higgs Boson at the Large Hadron Collider

**Aleandro Nisati**

**Abstract.** In the Standard Model of particle and fields, the non–zero vacuum expectation value of the Higgs field breaks the electroweak gauge symmetry, giving mass to the gauge bosons and elementary fermions. Its quantum is a spin–0 particle, the Higgs boson: this scalar is the only missing elementary particle of this theoretical model. A brief overview of the searches for this particle performed in the last decades is given. In particular, the latest results of the search at the Large Hadron Collider are summarized and discussed, focusing on the recent observation by the experiments ATLAS and CMS of a new boson with mass around 125 GeV. Preliminary results based on available data show that this particle is consistent with the boson predicted by the Standard Model.

Key words: Higgs boson, Electroweak symmetry breaking, LHC, ATLAS, CMS, CERN

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# 1 A Short Introduction

The Standard Model (SM) of particle physics describes the properties and the interactions of the fundamental constituents of all the visible matter in the Universe. It reproduces successfully the data observed in a myriad of experiments, performed mainly in particle accelerator facilities. All fundamental particles predicted by this theory have been all found in nature, except the Higgs boson, the quantum of the Higgs field, whose interaction with elementary bosons breaks the electroweak symmetry, and determines the appearance of their mass. Without this field, particles such as electrons and quarks would be massless, in strong contrast with the experimental observations. The consequences for our Universe of elementary particles with no mass would be dramatic. For example, even if hadrons, such protons and neutrons, acquire mass thanks to the Fermi motion and the binding energy of their constituents (quarks and gluons; only ~ 3% of the proton mass is due to the quarks mass), atoms with massless electrons would not exist, as the binding energy would be vanishing.

In SM, there is one isodoublet complex scalar field, thus described by four real scalar fields. After spontaneous electroweak symmetry breaking, one physical degree of freedom is left, the Higgs boson, while the other three degree of freedom are absorbed to build the longitudinal components of the $W^{\pm}$ $Z^{0}$ vector bosons and generate their masses. Yukawa interactions of this field with fermion fields generate masses of leptons and quarks. In this model the Higgs boson mass is not predicted. Once assigned, all physics properties of this scalar, with CP=+1 quantum number, are defined.

This paper is organized as follows: Section 0 presents a brief history on the proposal made to explain the electroweak symmetry breaking in SM with the introduction of a scalar field; Section 0 gives a short overview of the results on the search for the Higgs boson at past experiments, while Section 0 gives the results on the search for this scale at the Large Hadron Collider (LHC) by the experiments ATLAS and CMS, available on July 2013.

## 2 The Formulation of the Higgs Mechanism

The idea of introducing the spontaneous symmetry breaking in particle physics is due to Nambu (Nambu 1960a, 1960b) and Jona–Lasinio (Nambu, Jona–Lasinio 1961). The proposal, was based on the theory developments in condensed–matter, and applied to particle physics by several authors. In 1962 Anderson (Anderson 1963) discussed consequences of th proposed mechanism, but did not develop a relativistic model. The first formulation of the Higgs boson dates back to 1964 (Englert, Brout; Higgs; Guralnik, Hagen and Kibble 1964; Guralnik 2009). Lather, it was included in Standard Model, thanks in particular to the work made by Weinberg and Salam (Weinberg 1967; Salam 1968). Few years later, in 1971, 't Hooft ('t Hooft 1971; 't Hooft and Veltman 1972) demonstrated that this model allows calculable predictions of elementary particle processes, such us cross–sections and decay branching fractions; this was a major step for the consolidation of Standard Model. From 1973 onwards, an impressive series of experimental observations produced strong support in favour of this model: from the discovery of neutral currents to the discovery of the vector bosons $W^{\pm}$ and $Z^0$ (1983). More details on the A historical profile of the Higgs boson can be found here (Ellis, Gaillard, Nanopoulos 2012).

## 3 Higgs Boson Searches in the Past

As stated above, SM does not predict the Higgs scalar mass. However, it can be constrained by the many electroweak measurements available by a large number of experiments made in the past. This combination limits the mass of this particle to $m_H < 158$ GeV at 95% confidence level (ALEPH, CDF, D0, DELPHI, L3, OPAL, SLD Collaborations 2010). Direct searches were made by the experiments ALEPH, DELPHI, L3 and OPAL at LEP2 at CERN, studying electron–positron collisions up to $\sqrt{s} = 209$ GeV. No evidence of the production of this particles was found, and a limit $m_H > 114$ GeV at 95% CL was placed (LEP Working Group 2003). Direct searches were also made by the experiments CDF and D0 at the Tevatron collider (Fermilab, Chicago) where protons ad anti–protons were collided at the energy up to $\sqrt{s} = 1.96$ TeV. Searches were conducted for a Higgs boson mass in the range 100–150 GeV since early 1990's, with no evidence of the production of this particle, till the end of 2011. In a seminar held at CERN on December 13th, 2011, the ATLAS and CMS collaborations at LHC (CERN; see next section), announced the observation of an excess of events in proton–proton (pp) collisions at $\sqrt{s}=7$ TeV, consistent with the production of the SM Higgs boson, based on the analysis of 4.9 $fb^{-1}$ data. The local significance of this excess was about three standard deviations per experiment (ATLAS Collaboration 2012a; CMS Collaboration 2012a).

In summer 2012, using a data set corresponding integrated luminosities up to 9.7 $fb^{-1}$, an excess of events in the data was observed by CDF and D0 at Tevatron compared with the background predictions, in the search for the SM Higgs boson produced in association with a W or Z and decaying to bottom–antibottom ($b\bar{b}$) final states (CDF and D0 Collaborations 2012). Combining the findings of both experiments, the local significance of the excess (mostly in the mass region 120–135 GeV) was found to be about three standard deviations (CDF and D0 Collaborations 2012). At the same time, at CERN, on July 4th 2012, ATLAS and CMS confirmed the early observation announced in December 2011 using the first ~ 6 $fb^{-1}$ of data taken at $\sqrt{s}=8$ TeV in combination with the 7 TeV data sample. It was shown that the excess increased to about five standard deviations per experiment, and hence the discovery of a new particle at about 125 GeV mass was announced (ATLAS Collaboration 2012b; CMS Collaboration 2012b). More details are given in the section below.

## 4 Higgs Boson Searches at the Large Hadron Collider

### 4.1 The Large Hadron Collider

The Large Hadron Collider is to date the largest and highest–energy particle accelerator ever built. Approved by the CERN Council of December 1996, the construction of this accelerator started in 1998, in the LEP tunnel (Brunning 2004). A nice recollection is available here (Evans 2010). This machine has been primarily designed to collide protons at a centre–of–mass energy $\sqrt{s}=14$ TeV with a nominal luminosity of $L = 10^{34}$ $cm^{-2}$ $s^{-1}$ and a bunch spacing of 25 ns. Details on the design of this accelerator can be found in bibliography. The LHC has been designed to accelerate heavy ions as well. Four main experiments have been installed around the ring: two general purpose detectors, ATLAS and CMS, a detector to study heavy flavour physics, LHCb, and a detector optimized for the heavy ion collisions studies. LHC operations started in December 2009. In 2011 this accelerator collided protons at $\sqrt{s}$=7 TeV, delivering about 6 $fb^{-1}$ of integrated luminosity; in 2012 the centre–of mass energy was increased to $\sqrt{s}$=8 TeV and an integrated luminosity of more than 23 $fb^{-1}$ was delivered. In both cases the bunch spacing was set to 50 ns. The results reported in this paper are based on the 2011 data, plus the first 6 $fb^{-1}$ data collected in 2012, and was reported at the 2012 ICHEP Conference (Melbourne) and published soon afterwards.

## 4.2 Production of the Higgs Boson at the LHC

The dominant production mechanism at hadron colliders for the SM Higgs boson is so called "gluon–gluon" fusion process (ggF); other important processes are the Vector Boson Fusion (VBF) and the production in association with vector bosons W and Z (VH). SM Higgs boson searches at the LHC take the advantage of large production cross–sections, about a factor 10 more than the values at the Tevatron collider. Large centre–of–mass energy and luminosity are both crucial to the production of this particle with significant rates. In the region of $m_H$ ~ 120 GeV, the rare decay mode $H\rightarrow\gamma\gamma$ is *gold–channel*, thanks to the high mass–resolution that both ATLAS and CMS experiments have on the reconstruction of diphoton final states. High–mass resolution is also available in the $H\rightarrow ZZ^*\rightarrow lll'l'$ decay mode (with $l,l'$=e,μ); this final state is characterized by low rates and by high signal/background ration, and represents another crucial decay mode for the search for this boson with masses down to ~ 120 GeV. Still in the region of low mass ($m_H < 2m_Z$, where $m_Z$ is the Z–boson mass), decay modes such as $H\rightarrow b\bar{b}$ and $H\rightarrow\tau+\tau-$ are also very important in particular for production associated with vector bosons or for VBF processes. For Higgs boson masses in the region 150 GeV $\leq m_H \leq 2m_Z$ the most important decay modes are $H\rightarrow ZZ^*\rightarrow lll'l'$ and $H\rightarrow WW^{(*)}\rightarrow l\nu l\nu$. For larger mass, in addition to the gold–channel $H\rightarrow ZZ\rightarrow lll'l'$ and $H\rightarrow W^+W^-\rightarrow l\nu l\nu$, decay modes $H\rightarrow ZZ\rightarrow ll\nu\nu$, *llqq* and $H\rightarrow W^+W^-\rightarrow l\nu qq$ are also important. An useful review of the Standard Model Higgs boson phenomenology is here (Djouadi 2008).

## 4.3 The ATLAS and CMS Experiments at the LHC

ATLAS (A Toroidal LHC Apparatus) and CMS (Compact Muon Solenoid) are the two general purpose detectors at LHC. Their basic structure is very similar, though they are complementary on many technological choices. The three major sub–systems of ATLAS (ATLAS Collaboration 2008) are the tracking detector, the calorimeter and the muon spectrometer. At the core of the ATLAS detector is the inner tracking detector, of about 2 m diameter, which is immersed in a 2 T axial field produced by a superconducting solenoidal magnet. Silicon and micro–strip detectors, as well as a straw tube tracker, provide measurements of charged particle trajectories produce in the p–p collision. The central solenoid is surrounded by the calorimeter system. The electromagnetic calorimeter is based on a sampling lead/liquid–argon device. An iron–scintillator calorimeter placed around the electromagnetic calorimeter provides detection and measurements of hadrons, and it acts also as filter for muons produced in the collision. The muon spectrometer is based on three air–core superconducting toroidal magnets instrumented with precision drift tubes, as well fast cathode readout detectors used for trigger and offline measurement. The dimensions of ATLAS are 25 m diameter, 44 m in length; the overall mass is of 7,000 tonnes.

The central feature of the CMS detector (CMS Collaboration 2008) is a superconducting solenoid 13 m long and with 6 m diameter, which provide an axial field of about 3.8 T. The bore of the solenoid is instrumented with particle detection systems. The steel return yoke outside the solenoid is instrumented with gas detectors used to identify and measure muons. Charged particles are measured by silicon and pixel detectors; no use of gaseous detectors is made. A lead–tungestate crystal electromagnetic calorimeter and a brass/scintillator hadron calorimeter surround the tracking volume. Both calorimeters are contained in the solenoid cavity. As in ATLAS, the outermost component of the CMS detector is the muon system, consisting of gaseous detectors interleaved in the iron plates belonging to the magnet return yoke.

Photons, electrons, muons of 100 GeV transverse momentum emitted in the central pseudorapidity region are measured by these detectors with resolutions of the order of 1% or less. Hadron jets and taus with that energy are measured with resolutions better than 10%. This performance places the ATLAS and CMS detectors in an ideal position for the search for the SM Higgs boson.

## 4.4 Searches for the Higgs Boson with ATLAS and CMS

In this section the results found by ATLAS (ATLAS Collaboration 2012b) and CMS (CMS Collaboration 2012b) experiments based on the studies of the diphoton and the $ZZ^* \rightarrow ll l' l'$ ($l=e,\mu$) final states are presented. The data sample analysed corresponds to about 5 $fb^{-1}$ collected in 2011 and the first 6 $fb^{-1}$ collected in 2012.

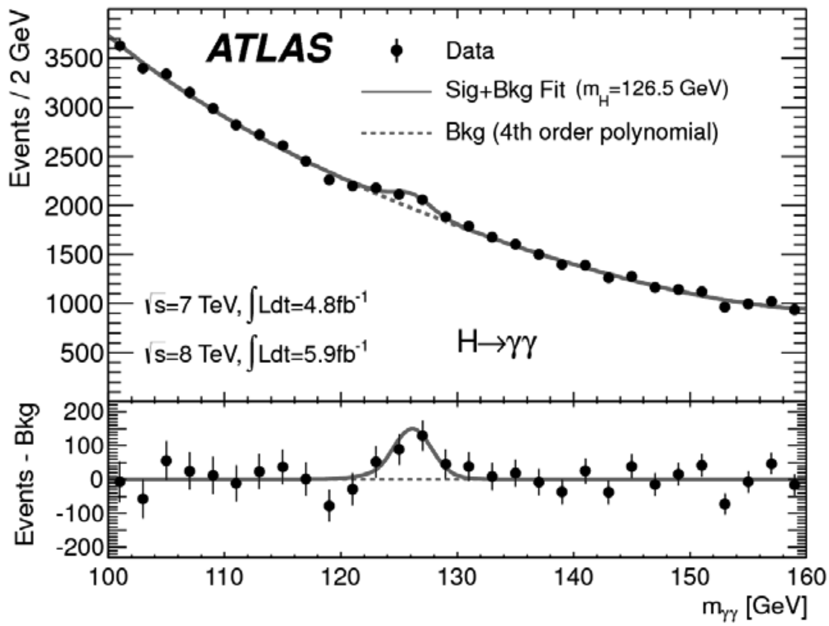


**Fig. 1** Distribution of the diphoton invariant mass in ATLAS[1]

[1] Distribution of the invariant mass of diphoton candidates after all selections for the combined 7 TeV and 8 TeV data sample. The result of a fit to the data of the sum of a signal component fixed to $m_H$ = 126.5 GeV and a background component described by a fourth-order Bernstein polynomial is superimposed. The residuals of the data with respect to the respective fitted background component are displayed in the bottom plot.

The Fig. 1 shows the invariant mass $m_{\gamma\gamma}$ distribution of $\gamma\gamma$ pair reconstructed in the $100<m_{\gamma\gamma}<160$ GeV mass–window by the diphoton analysis of the ATLAS data. The study is based on the analysis of isolated, high transverse momentum ($p_T$) photons that selects a total of 59039 events. This spectrum is well explained by the Standard Model $\gamma\gamma$ continuum (*irreducible background*), plus contributions from $\gamma$–jet and jet–jet processes where the jet is misidentified as a prompt photon (*reducible background*). The background composition has been measured and compared with Monte Carlo predictions. About 76% of the events are from $\gamma\gamma$ continuum, the remaining is from the reducible background; this shows an excellent purity of genuine photon selected after analysis cuts. The single photon reconstruction and identification efficiency depends on the photon $p_T$; it is 65%(95%) for $p_T$=25(80) GeV. The diphoton mass resolution is predicted to be 3.9 GeV full–width half–maximum. The invariant mass distribution can be fitted with quite a few empirical analytical functions that have been carefully studied using Monte Carlo samples. The chosen function (a fourth–order Bernstein polynomial) describes satisfactorily the data except in a narrow mass interval around 126 GeV: an excess of event is visible on top of the expected background. The local probability that this excess is due to background fluctuation has been evaluated to be 4.5σ[2]. Similar results have been found by CMS.

The 4–lepton channel offers an excellent mass resolution ($O(1\%)$) associated to an excellent signal–to–background ratio ($O(1)$), thanks to the accurate full reconstruction of this final state. Also in this case, the analysis proceeds with the selection of two pairs of isolated, high–$p_T$, opposite charge, same–flavour leptons (electron or muon) with one pair having the reconstructed invariant mass consistent with the Z–mass. Leptons are also required to be well associated to the proton–proton collision vertex. The Fig. 2 shows the invariant mass $m_{4l}$ of the 4–lepton system after full event selection, as measured by CMS, in the mass range

[2] In order to increase the sensitivity to the SM Higgs boson signal, the events have been divided in 10 categories, depending on the direction of the two photons, their transverse momentum, the fact that none, one or both undergo a bremsstrahlung process in the material of the inner detector. The statistical significance of the excess is the combination of the statistical significance in each individual category.

from 70 to 180 GeV. The resonance reconstructed around $m_{4l} \sim 90$ GeV is explained by Z–boson decays in 4–lepton final states (where the pair of additional leptons is produced by virtual bremsstrahlung photons from initial or final state radiation).

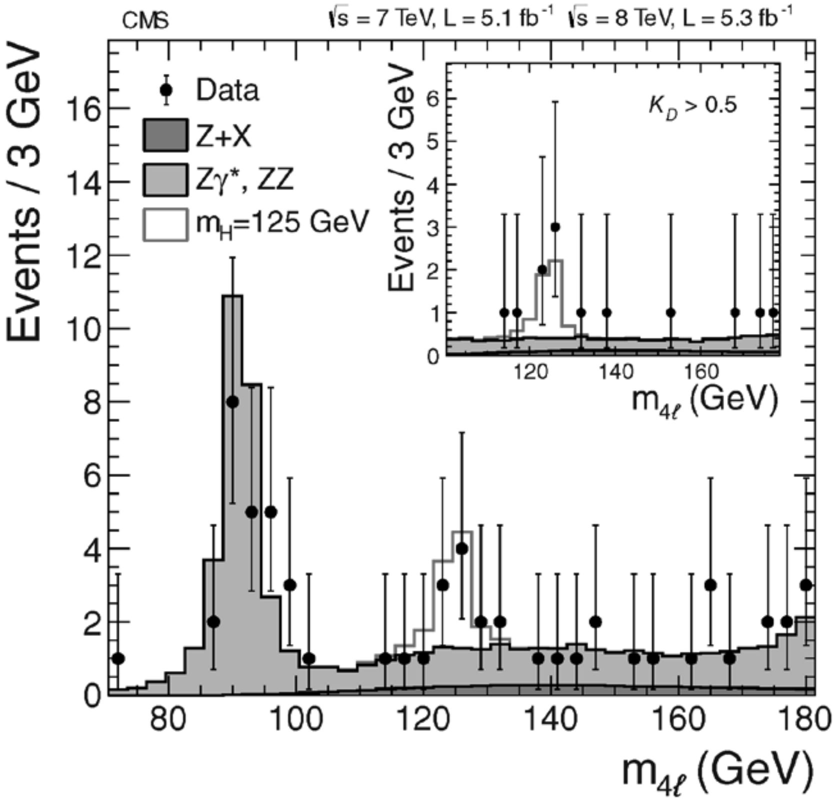


**Fig. 2** Distribution of the 4–lepton invariant mass in CMS[3]

[3] Distribution of the four-lepton invariant mass for the ZZ→4l analysis. The points represent the data, the filled histograms the background, and the open histogram shows the signal expectation for a Higgs boson of mass $m_H$ =125 GeV, added to the background expectation. The inset shows the mass distribution for a tighter selection.

In a SM without Higgs boson, the events excepted above $m_{4l}$ ~ 90 GeV, visible in the coloured histogram, are due to the ZZ* irreducible background, and to Z+jets reducible background, where a lepton pair is produced by heavy flavour decays, and/or by jets mis–identified as electrons or muons. These prediction reproduces the observed data, expect in tight region around $m_{4l}$ ~ 125 GeV where, also for this final state, and excess of events is observed. In the mass window 121.5 GeV – 130.5 GeV, 9 events are observed while 3.8±0.5 events are expected. The local probability that this excess is due to background fluctuation has been evaluated to be 3.2σ (expected 3.8σ). The mass resolution for masses around 125 GeV is expected to be 1.2 GeV (1σ). Similar results have been found independently also by ATLAS.

The results obtained in these two individual channels have been combined to get the overall significance of the observed excess. Both ATLAS and CMS have included also the results of the analysis of the channel H→*WW**→*lνlν*, given the sensitivity of this decay mode in the mass region in discussion with the analysed data. In addition, CMS has also included the findings of the searches for $H\rightarrow\tau^+\tau^-$ and $H\rightarrow b\bar{b}$ (produced in association with vector bosons) final states.

The combined local probability (called $p_0$), as a function of the hypothesized Higgs boson mass, for the background to fluctuate and produce the excess observed by ATLAS is shown in Fig. 3.

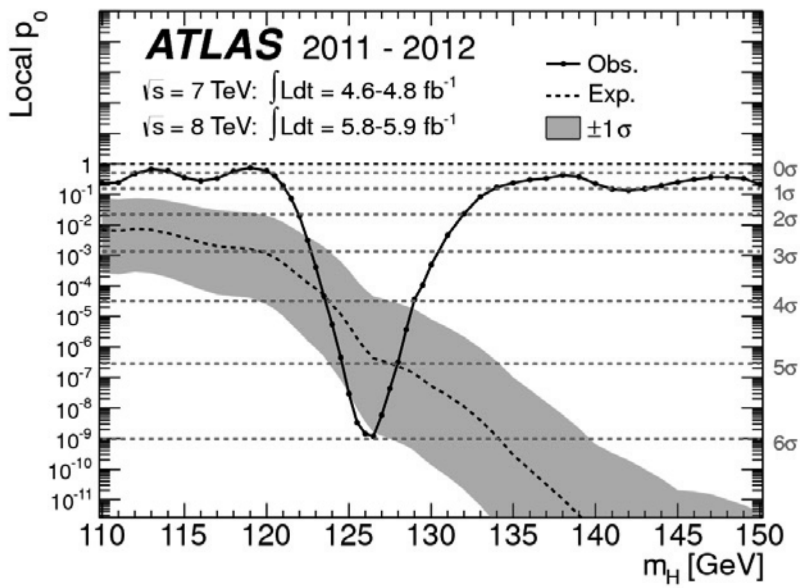


**Fig. 3** The observed local p0 as a function of $m_H$ in the low mass range in CMS[4]

As it is possible to see, this probability reaches the value of 5.9σ for $m_H$ ~ 126 GeV. Similar results are obtained by CMS for $m_H$ ~ 125 GeV (which is fully compatible within statistical and systematic uncertainties with the mass where ATLAS gets its maximum significance). We are in presence of the production of a new neutral particle, with a mass value of about 125 GeV, candidate to be the Higgs boson predicted by the Standard Model.

[4] The observed (solid) local p0 as a function of mH in the low mass range. The dashed curve shows the expected local p0 under the hypothesis of a SM Higgs boson signal at that mass with its plus/minus one-sigma band. The horizontal dashed lines indicate the p-values corresponding to significances from 1 to 6 sigma.

## 4.5 Future plans and perspectives

The discovery of this new particle opens a new research field in high–energy physics. It is important now to determine its physics properties and compare them with those predicted by Standard Model for the Higgs boson: mass, natural width, spin and parity, couplings to elementary fermions and bosons. LHC can do all these measurements, except the intrinsic width (expected for the SM Higgs boson to be about 4 MeV) for which most likely only limits can be put, because the experimental mass resolution. A high–luminosity upgrade of LHC (HL–LHC), if approved by CERN Council, will allow reaching the ultimate accuracy on the determination of the nature of this particle that is possible to achieve by this collider.

In parallel, the search for possible partners of this new particle will continue: the discovery of an additional Higgs–like boson would unambiguously indicate that this object is not be the Higgs boson predicted by Standard Model, and that New Physics is at the energy scale accessible with the Large Hadron Collider.

# 5 Conclusion

A short overview of the search of the Standard Model Higgs boson at the LHC with the ATLAS and CMS experiments, studying proton–proton collisions, has been given. The search has been performed with a dataset correspondent to an integrated luminosity of about 5 $fb^{-1}$ taken at $\sqrt{s} = 7$ TeV (2011), and of about 6 $fb^{-1}$ taken at $\sqrt{s} = 8$ TeV (2012). An excess of events with significance of 5 standard deviations has been observed by both experiments in particular in the high mass–resolution decay modes $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ^* \rightarrow ll l'l'$ ($l'=e,\mu$) around a mass value of about 125 GeV. The results provide conclusive evidence for the discovery of a new particle consistent with the Higgs boson predicted by Standard Model, within the theoretical and experimental uncertainties on the measurements published at the time of writing of this paper. The data that will be provided by the LHC in future run at an energy of $\sqrt{s} \approx 14$ TeV and with much larger integrated luminosity will be crucial to establish the nature of this new particle, and its consistency with the Standard Model Higgs boson.

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# The Qiqi Tushuo by the Jesuit Johann Schreck: Europeans Theatra Machinarum in China in the 16th Century

**Michela Cigola**

**Abstract.** This article aims to investigate the role played by various missionaries of the Society of Jesus in the development and spread of European scientific and mechanical knowledge in China in the XVI$^{th}$ century and specially by Johann Schreck (1576–1630); Chinese name Deng Yuhan). Schreck was a jesuit with a wide range of interests and vast scientific and literary culture. He studied in Germany, France and Italy, where he became a disciple of Galileo Galilei (1564–1642).

Key words: Theatra Machinarum, Chinese History of Science, Mechanical Engineering History, Jesuits History

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## 1 Johann Schreck and his Work

Johann Schreck (1576–1630) was a scholar with broad interests and a great scientific and literary culture, he studied botany, mathematics and astronomy. In 1590 he started to study at the University of Freiburg. At first he studied at the Faculty of Arts, but he also studied medicine, languages, law and sciences. In 1603, he became disciple of Galileo Galilei (1564–1642) in University of Padua. After meeting Galileo he Latinised his name to Johannes Terrentius (1589– c. 1644). In 1610, he arrived in Rome and entered the circle of Federico Cesi, scientist and naturalist from a noble Italian family and founder of the *Academia dei Lincei*. The aim of the Academy was to promote free and autonomous scientific research, and many of the best minds in Italy and Germany joined it. Galileo became a member of the academy in April 1611, followed immediately by Johann Schreck in May of the same year. Just a few months later, in November 1611, Schreck decided unexpectedly to join the Society of Jesus and left the academy, while maintaining contacts with his Academy friends. His abandonment of the Lincei caught other academics by surprise, to the extent that Galileo wrote a letter to Federico Cesi in which called the fact that JS had become Jesuit "[...] a great loss [...]"[1].

During his theology studies, he met Nicolas Trigault (1577–1628), who persuaded him to become a missionary in China and travel with him to the courts of Europe. Together with his portrait of Trigault, Rubens' portrait of a Chinese missionary dates to this period. Although not specifically mentioned, it is possible that the Jesuit portrayed is Johann Schreck, who was Trigault's companion on the journey around the courts of Europe, and therefore might have come into contact with Rubens while he was portraying Trigault (See Fig. 1).

[1] "Lettera di Galileo a Federico Cesi (in Roma). Firenze 19 dicembre 1611". (Biblioteca dell'Accademia dei Lincei. Mss. 12 , car. 135).

**Fig. 1** P. P. Rubens, portrait of a Jesuit missionary[2]

He started his journey to China in April 1618 from Lisbon, in 1621 he arrived in Hangzhou, and in late 1623 Beijing. Upon his arrival in China, Schreck and his confrères began working on the systematic translation of European scientific knowledge into Chinese. One of the most important of these translated works is the *Qiqi tushuo* (Diagrams and explanations of the wonderful machines of the Far West) with Wang Zheng in 1627, a kind of encyclopaedia of European mechanical knowledge in Chinese. The volume contained commented reproductions taken from the works of the French Besson, Italians Ramelli and Zonca, hungarian Faustus Verantius and from German Heinrich Zeising.

## 2 European Theatra Machinarum

Jacques Besson (1540–1576) was the first to introduce a text in France with purely mechanical representations, drawing on Renaissance treatises

[2] It is drawn in Antwerp (*Flandres*, Belgique) on January 17, 1617. Credit: Rubens drawing of a man in Korean costume. Paul J. Getty Museum (Malibu) Acquisition 1983. See via: www.getty.edu .

on the subject. In 1569, King Charles IX appointed him *Maître du roi des machines* (King's master of machines); following the appointment, he moved to Paris where he began his *Théâtre des instruments et machines* (Theatre of instruments and machines), written and published in Latin and followed by other editions in French, German, Italian and Spanish. The volume consists of 60 plates, representing various devices including mills, lifts for weights and saws, as well as wagons and equipment for docks work. All the machines are represented in a three–dimensional perspective, taking up an entire page and surmounted by an explanatory title in capital letters.

Agostino Ramelli (1531–ca.1600) served in the army of Charles V, reaching the rank of captain, after studying mathematics and architecture. After being appointed engineer for the Duke of Anjou, the future King Henry III (1551–1589), he moved to France. His *Le diverse ed artificiose macchine* (The Various and Artifactitious Machines) is the only work he published. Published in Paris in 1588, it consists of 195 chapters, each of which contains the illustration and description in French and Italian of a different machine. In most cases, they are machines for lifting water (norias, Archimedes' screws and, above all, a great variety of pumps), but there are also various types of mills, hydraulic saws and other machines driven by the force of the water, as well as cranes, fountains and instruments of war. In the volume, machines are placed in natural environments and are represented in pseudo perspective with refined lighting effects. Each machine takes up a whole page surrounded by a thick decorative frame within which the number of the figure is placed.

Vittorio Zonca (1568–1602) architect of the city of Padua, is best known for publishing the *Novo Teatro di machine et edificii per varie et sicure operazioni* (New Theatre of Machines for Various and Safe Operations), a text that features 42 mechanical and hydraulic devices, including various presses, construction machinery, mills and more. The book was published in 1607, five years after his death. The work presents machines in natural or architectural environments, and great care is taken with three–dimensional perspectives and treatment of chiaroscuro. Each figure takes up a full page within a box topped by another box containing a brief description in capital letters.

Faustus Verantius (1551–Venezia 1617) born in Dalmatia but a citizen of the Republic of Venice, is remembered for his book *Machinae Novae* which contains 49 illustrations, all double–page with the title in the background in capital letters. The figures illustrate various machines, but also bridges, boats, watches and some architectural drawings. The devices, whose settings are much more measured and concise than in previous treatises, are accompanied by a description in five languages, Italian, Latin, German, Spanish and French. In drawing up his work, Veranzio owed much to the wealth of knowledge accumulated by writers of earlier centuries, such as Leonardo da Vinci (1452–1519), Mariano di Jacopo, called Taccola (1382–c. 1453) and Francesco di Giorgio Martini (1439–1501).

Heinrich Zeising about whom very little is known, was active in first quarter of 17$^{th}$ century and, in 1613 in Leipzig, published his *Theatrum Machinarum*, divided into a number of books describing 140 assorted devices, including many machines. The work synthesises the treatises of Besson, Ramelli and Zonca. In fact, Zeising redesigns the machines described in these treatises and places them in very complex environments with strong chiaroscuro, populated by many characters. All drawings are full–page, with the number at the top in Roman numeral.

## 3 Schreck's Qiqi Tushuo

Schreck drew on all these treatises for the drafting of his *Qiqi tushuo.* It is quite clear that he made use of the science and technology library that he and Nicolas Trigault had patiently put together during their travels through the courts of Europe and then taken as far as China. It should not be forgotten that for some years, first as a disciple of Galileo and then as a member of Accademia dei Lincei, Schreck had frequented Europe's most vibrant cultural environment and had certainly acquired the knowledge that he was to re–use in his works from the Chinese period. Let us now analyse the *Qiqi tushuo,* comprising 81 illustrations, almost all full–page and only some double–page, for a total of 73 drawings. From the graphic organisation of the pages, it seems that Schreck was closely inspired by the work of Zonca, whose layout he faithfully copied, with a large box and the upper part dedicated to a description of the device.

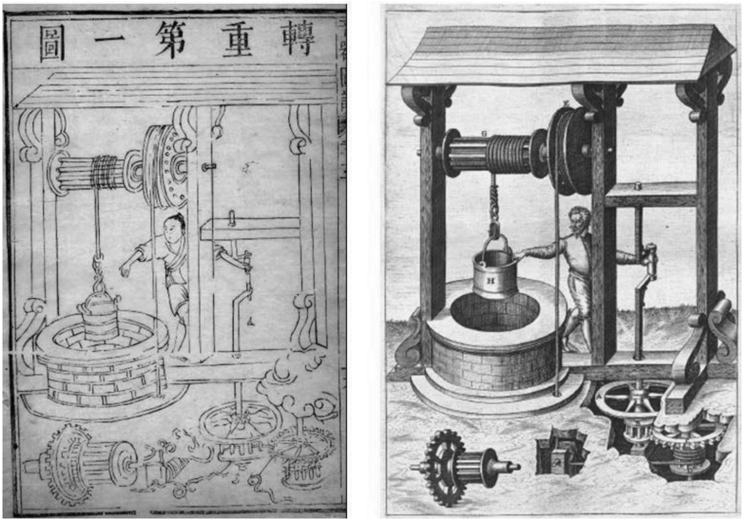


**Fig. 2** Comparison of two wells. (l) image from *Qiqi tushuo* by Schreck, (r) image from *Le diverse et artificiose machine* by Ramelli[3]

Comparising a well's drawing in Schreck work with a well taken from the work of Ramelli (See Fig. 2), it is evident that the general layout of the drawing is identical in the choice of the depth of perspective and in every small detail, even if it completely lacks graphic connotations of materials (such as the wood of the uprights or the ground on which the well stands). In Ramelli's drawing, the representation is mature and therefore more correct from the point of view of three–dimensional treatment.

[3] Schreck 1627, p 267; Ramelli 1588, plate 85.

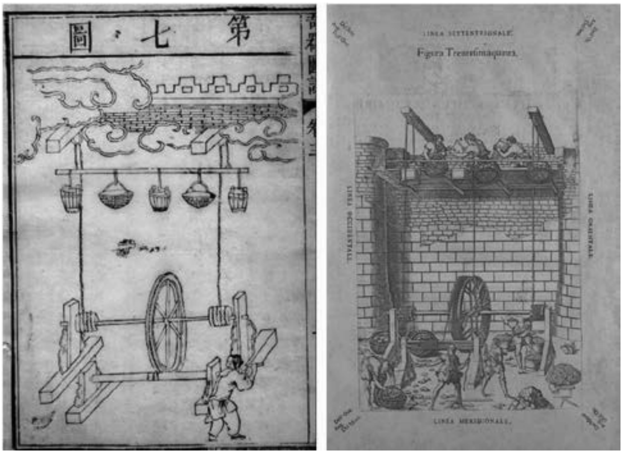


**Fig. 3** Comparison of two construction machine. (l) image from *Qiqi tushuo*, (r), image from *Il teatro degli Istrumenti* by Besson[4]

Now a comparison between Schreck's work and Besson's work (see Fig. 3); the device is a lift for weights to be used on building sites. The original drawing shows a group of workers intent on their work, both on the ground and on scaffolding. Schreck, however, reduces the setting to a minimum, leaving only a small portion of crenelated masonry at the top. He also almost completely eliminates the human presence, which is reduced to a single machine operator indispensable for clarifying the functioning.

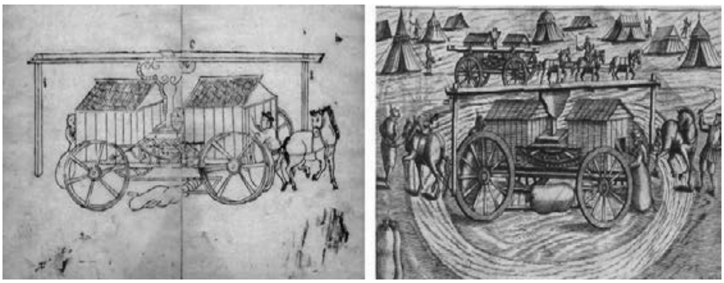

**Fig. 4** Comparison of two Mobile field mill. (l), image from *Qiqi tushuo* by Schreck, (r), image from *Novo Teatro di Machine* by Zonca[5]

[4] Schreck 1627, p 249; Besson 1579, plate 35.
[5] Schreck 1627, pp 301–302; Zonca 1607, folio 89v

Now let us make a comparison with Zonca's drawing (See Fig. 4), analysing a double–page drawing from *Qiqi tushuo,* which represents what at first sight appears to be a wagon. We find the same wagon in the work of Zonca, but from his drawing we learn that the wagon is actually a mobile field mill to produce flour for making bread for troops on the battlefield, invented by Pompeo Targone (1575–1630), an italian inventor who served under the French and helped their army significantly in the wars against the Huguenots thanks to its military machines and illustrated for the first time by Zonca. The Chinese text focuses on the wagon–mill, completely eliminating the naturalistic setting, but rather placing it in an aseptic, completely empty environment. This concession to synthesis is not applied to representation of the device, which instead slavishly copies that illustrated in the Italian version, in terms of both the three–dimensionality of the whole and the details of the animated beings surrounding it.

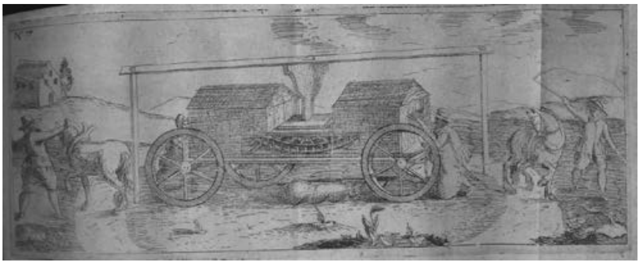

**Fig. 5** Mobile field mill[6]

The discrepancy between the *Qiqi tushuo* and the Italian treatise immediately becomes clear when the drawing taken from Zeising's treatise is added to the comparison (see Fig. 5). The German treatise offers a first synthesis and abstraction of Zonca's drawing; in fact, the natural setting is maintained but simplified to the maximum, and all the details in Zonca's treatise that indicate the belligerent use of the wagon–mill are eliminated. In this case, Schreck did not use the original drawing but probably the drawing from Zeising's work, simplifying and further synthesising it.

[6] Zeising 1613, plate 7.

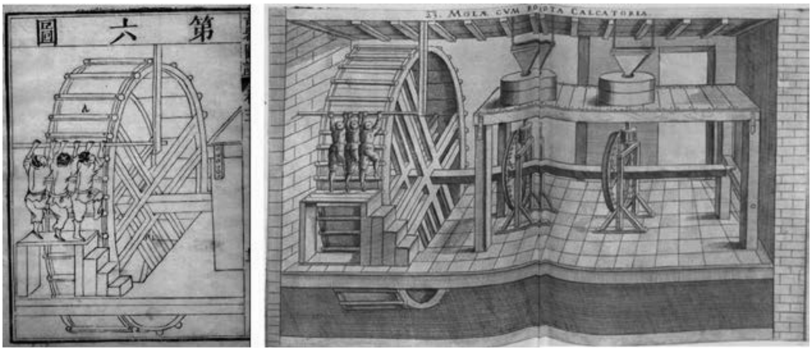


**Fig. 6.** Comparison of two rotating treadmill. (l), image from *Qiqi tushuo* by Schreck, (r), image from *Machine novae* by Verantius[7]

The last comparison is with the work of Veranzio (see Fig. 6), from which we analyse a double–page drawing which, as the title indicates, represents a mill with a rotating treadmill, that is with a wheel turned by the power of the men inside it. In this case, it is extremely interesting to see how Schreck in his illustration has decided to include only half of Veranzio's drawing, that is the part with the wheel, feeling that the part showing the rest of the mill is useless or uninteresting. This latter is identical to the original in every detail, even the most minute.

## 4 Conclusion

In addition to his activities of mechanical dissemination, Schreck wrote and translated several Chinese textbooks on mathematics, engineering, medicine and astronomy. Schreck is said to have died in 1630, may 11$^{th}$ at the age of 54, of a medical experiment on himself. He is laid to rest on the Beijing cemetery of Zhalan.

[7] Schreck 1627, p 305; Verantius 1615, plate 23.

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# Willem Jacob 's Gravesande's Methodological Views

**Steffen Ducheyne**

**Abstract.** That 's Gravesande (1688–1742) did not follow Newton's doctrines *ad literam* has been frequently observed in the literature. Yet, despite such mitigation of 's Gravesande's Newtonianism, it has frequently been maintained that he was an advocate of Newton's methodology. Here I shall argue that, although 's Gravesande took over key terms of Newton's methodological canon, upon close scrutiny, his methodological views were quite different from and occasionally even incongruent with Newton's views on the matter.

Key words: Scientific methodology, 's Gravesande, Newton

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## 1 A Short Introduction

Willem Jacob ‘s Gravesande (1688–1742) has traditionally been portrayed as a “Newtonian” (Cohen 1956, pp 234–243; de Pater 1994, p 261; Schofield 1970, Chap. 7) and even as a “Baconian Newtonian” (Schofield 1978, pp 179–180). He was, we are told, “one of the most influential advocates of Newtonianism on the Continent” (de Pater 1994, p 257). During his stay in England in 1715, he was introduced to England’s leading natural philosophers: Isaac Newton, who was president of the Royal Society at the time, the Royal Society’s curator of experiments, John Theophilus Desaguliers, (1683–1744) and the Savillian Professor of Astronomy at Oxford, John Keill (1671–1721) who had begun teaching Newton’s natural philosophy “*by* Experiments *in a mathematical Manner*” around 1704 or 1705 (Desaguliers [1734–1744] 1763, p viii). In June 1715, ‘s Gravesande was elected Fellow of the Royal Society and during his stay in England he was won over by the Newtonian cause, the story goes. Shortly after his return, in 1717, he became professor of mathematics and astronomy at the University of Leiden, where he taught Newton’s natural philosophy. In 1720–1721 the first edition of ‘s Gravesande’s *magnum opus* appeared – a work which carried the telling title *Physices elementa mathematica experimentis confirmata, sive introductio ad philosophiam Newtoniam* (’s Gravesande 1747, 1742). *Physices elementa* went through three editions during ‘s Gravesande’s lifetime. Due to its publication, ‘s Gravesande soon acquired an international reputation as a premier Newtonian. The above and other details have been frequently repeated in the literature and, for the most part, they have been used to highlight the close connexion between ‘s Gravesande and Newton.

*Prima facie* there are good reasons for portraying ‘s Gravesande as a ‘Newtonian’, for *Physices elementa* contained the basic doctrines of Newton’s natural philosophy. However, ‘s Gravesande occasionally treated Newton’s doctrines in a selective manner: for instance, *Physices elementa* did not contain a discussion of Newton’s fits of easy transmission and reflection and the ether which Newton introduced to explain optical phenomena was left unmentioned. Moreover, ‘s Gravesande did not accept all of Newton’s doctrines without reservation, which is clear from the position he took in the *vis viva* dispute. In view of this, ‘s Gravesande’s oftentimes critical attitude towards Newton’s doctrines has been rightly highlighted. In the wake of the quibble over *vis viva* ‘s Gravesande signalled that being a Newtonian philosopher is not contingent upon whether one accepts Newton's doctrines *ad literam*; rather, a Newtonian philosopher is he who follows Newton's method ('s Gravesande 1747, I, p xi). 's Gravesande's 'Newtonianism' was therefore essentially *methodological*, or so it has been suggested: although he may have been selective in his endorsement of Newton's doctrines, his adherence to Newton's method was unremitting, it is claimed (Schofield 1970, p 140).

My main endeavour is to show that 's Gravesande developed a relatively autonomous methodological position. It is high time that we free 's Gravesande from his 'Newtonian straight jacket' and start seeing him in his own terms – i.e. as an fascinating eighteenth–century *dramatis persona* who, although he clearly took inspiration from Newton's natural philosophy, was running his own methodological agenda.

## 2 's Gravesande's Methodological Views

It was not until the (mid–)1730s that 's Gravesande developed a detailed account of scientific methodology. He elaborated on his methodological views in his *Introductio ad philosophiam, metaphysicam et logicam continens* (1736), which appeared two years after his appointment as professor *totius philosophia*.

Given 's Gravesande's clear rejection of hypotheses, it may *prima facie* come as a surprise that they occupied such a central place in his discussion of method. Paradoxically, 's Gravesande's preoccupation with hypotheses arose from his deep concern with certainty. He was acutely aware that the use of hypotheses was a significant and ineradicable aspect of natural–philosophical research. Given his concern with certainty, the following question came to occupy him: how can certainty arise from hypotheses? In this context, he set out to show that certainty can emerge from a careful scrutiny of hypotheses and to explicate the conditions under which a hypothesis can be transformed from a probable proposition into one which carries *moral certainty*. In the preface to the third edition of *Physices elementa* (1742), 's Gravesande wrote:

> I don’t deny but that Hypotheses may open the way to Truth; but when that is prov’ed to be true, which before was only suppos’d, there is no longer any room for Hypotheses.[1]

‘s Gravesande was, in other words, highly concerned with methodizing and constraining the use of (causal) hypotheses (’s Gravesande 1736, pp 292–294). Hypotheses are required in those cases in which we cannot directly arrive at certainty:

> In many given things, when we undertake to examine [them], we do not discover an open road by which we can arrive at certainty directly. Then probability is to be sought after, but oftentimes this is not granted unless by hypotheses, which, however, sometimes lead to such probability that they have to be taken for certainty.[2]

A hypothesis is defined as follows by ‘s Gravesande:

> By a hypothesis we understand something feigned by which one responds to a proposed question. One should act upon this fictitious response as if it were true; however, [our] reasoning should be directed in such a way that it gives occasion to explore whether the solution is true; moreover, we should never give assent to this [solution] as long as the truth is not established most clearly. This method of reasoning can have great use, but generally men abuse it miserably.[3]

When reasoning hypothetically, the following rules are to be followed:

> 1. The subject with which the question is concerned should be accurately examined and an extensive enough cognition of the subject is called for.
> 2. We should select from the circumstances [i.e. effects] some of the *main* [circumstances], namely [those] that have something noteworthy with respect to the others.
> 3. From these [circumstances] one [circumstance] is again separated and some of the ways in which this [circumstance] can take place are investigated.

[1] ‘s Gravesande 1747, I, p xii.
[2] ‘s Gravesande 1736, p 292.
[3] ‘s Gravesande 1736, pp 292–293.

> 4. It should be investigated whether among these causes there is a certain [cause], from which the rest of the circumstances, [which were] separated as prescribed by the second rule, follow; if such [cause] is present, then it makes itself the hypothesis to be explored.
> 5. The hypothesis is explored by applying it to all the other known circumstances so that it may be established whether it satisfies all [those circumstances] here.
> 6. The hypothesis itself should be examined and consequences are to be deduced from it so that new phenomena may be discovered and it should be investigated whether these [phenomena] really occur.[4]

The first to fourth rule pertain to the generation of hypotheses. The purpose of the third rule is to assemble those causes from which the *main* circumstances selected by the second rule can be derived ('s Gravesande 1736, p. 294). By the fourth rule one then selects from the list of causes obtained by the third rule the cause from which the rest of the *main* circumstances follow. This cause is the hypothesis to be investigated. The fifth and sixth rule explicate how hypotheses are to be tested. By the fifth rule we establish whether the hypothesis obtained by the preceding rule satisfies all other known phenomena. If it does not satisfy all the phenomena at hand, the hypothesis under consideration is to be rejected outright. When it truly satisfies all phenomena, our assessment of the hypothesis will depend on the number of phenomena that it successfully satisfies. If the number of phenomena that a hypothesis successfully satisfies is small, one should investigate whether another hypothesis may be found that successfully saves more phenomena. If such hypothesis successfully saves a larger number of phenomena, our doubt will vanish and "what could initially be considered as a mere fiction, will now be taken to be proved most clearly," i.e. the hypothesis is to be considered as certain ('s Gravesande 1736, p 297). When no such hypothesis can be found, our suspicion can frequently be removed by taking recourse to the sixth rule. By the sixth rule we investigate whether the hypothesis under consideration is able to predict previously unknown phenomena and whether these predictions are correct. When both conditions, as stipulated in the sixth rule, are fully met, then what was formerly a hypothesis has turned into a morally certain demonstration. If not, the hypothesis is to be considered as probable only. Those who call the proposition, which has

[4] 's Gravesande 1736, pp 293–297. Emphasis in italic style is mine.

successfully passed the conditions stipulated in the fifth or sixth rule a hypothesis, are mistaken:

> We see that certainty can be deduced from a hypothetical account and that those, who refer all such accounts to probability, err. They, who refer to an account which is directly deduced from observed phenomena as a hypothesis so that they only acknowledge to it probability, err all the more. Many fall into this error when they talk about the Newtonian explanation of the celestial phenomena, which they take for a hypothesis; whereas this most high man has laid down nothing which has not been deduced from indubitable phenomena by mathematical reasoning; […].[5]

It is worthwhile to call attention to some of ‘s Gravesande methodological assumptions. First of all, he considered a hypothesis’ capacity to successfully save the phenomena (cf. the fifth rule) and its capacity to successfully predict new phenomena (cf. the sixth rule) as criteria for a hypothesis’ truthfulness. Secondly, and more specifically, in order to be accepted as truthful on ‘s Gravesande’s terms, a hypothesis should not necessarily have the capacity to successfully save the phenomena and to successfully predict new phenomena at the same time. According to the fifth rule, a hypothesis which successfully saves a large enough number of phenomena achieves a demonstrative status and is therefore to be considered as truthful. Therefore, a hypothesis that meets the conditions as stipulated in the fifth rule does not, it seems, need to pass the conditions as stipulated in the sixth rule in order to be accepted as truthful. Yet, on the other hand, from his discussion of Huygens’ demonstration of Saturn’s ring it seems that ‘s Gravesande entertained the idea that a hypothesis should meet both the fifth and sixth rule in order to be considered as truthful:

> The hypothesis of the ring of Saturn not only explained already observed phenomena and agreed to their least circumstances, the phenomena deduced from this very hypothesis also [agreed to] the heavenly [phenomena] that were observed afterwards.[6]

[5] ‘s Gravesande 1736, pp 298–299.
[6] ‘s Gravesande 1736, p 298.

In this manner, ‘s Gravesande observed, Huygens proved the hypothesis under consideration beyond any doubt. Nevertheless, in his scientific practice ‘s Gravesande considered hypotheses that successfully save the phenomena as truthful. In other words, ‘s Gravesande accepted the truthfulness of a hypothesis – whatever its origin or status may be – when its deductive consequences are confirmed by experience. Such framework of theory confirmation is at odds with Newton’s views on the matter. As I have argued elsewhere, in order to avoid arbitrary speculation Newton insisted that the causes to be adduced in natural philosophy should be constrained by imposing the demand on them that they should be shown to be the necessary and sufficient causes of certain effects given the laws of motion, i.e. given a set of non–arbitrary principles which have been shown to be promising in the study of motion and which remain neutral with respect to the *modus operandi* of gravitation (Ducheyne 2012, Chaps. 2, 3). Put differently, according to Newton not just any cause will do in natural philosophy: true causes in natural philosophy are those causes which have been shown to be necessary and sufficient given a set of prioritized theoretical principles, *in casu* the laws of motion. ‘s Gravesande did not take any of these demands into consideration. Like Newton, however, he insisted on the prediction of new phenomena, but, yet again, this was not a methodological precept that was exclusive to Newton’s methodology: ‘s Gravesande could have perfectly been influenced by Huygens’ introduction to the jointly published *Traité de la Lumière* and *Discours de la cause de la pesanteur* (1690). Moreover, while for Newton the prediction of new phenomena was a test of the universality of a principle, which has previously been ‘deduced from phenomena’ by analysis, for ‘s Gravesande (and Huygens) it was a direct test of the truthfulness of a principle, regardless of its (theoretical) origin.

## 3 Conclusion

Although ‘s Gravesande was clearly inspired by Newton’s natural philosophy, he was integrating Newton’s legacy into his own intellectual agenda. ‘s Gravesande’s case shows how Newtonian and non–Newtonian elements were integrated into an eclectic, but nevertheless comprehensive account of *physica* – at least on our eighteenth–century *dramatis persona*’s understanding. That ‘s Gravesande did not follow Newton’s doctrines *ad literam* has often and correctly been observed in the literature. Yet, despite such mitigation of ‘s Gravesande’s *Newtonianism*, it has frequently been maintained that he was an advocate of Newton’s methodology. Here I have argued that, although ‘s Gravesande took over key terms of Newton’s methodological canon, upon close scrutiny, his methodological ideas were quite different from and occasionally even incongruent with Newton’s views on the matter. Correspondingly, in this essay I have tempered ‘s Gravesande’s alleged *methodological Newtonianism*.

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# The Helium Atom and the Majorana Solutions to the Two–Electron Problem

**Salvatore Esposito and Adele Naddeo**

**Abstract.** In 1920s the failure of the old quantum theory by Niels Bohr (1885–1962) and Arnold Sommerfeld (1868–1851) to describe successfully two–electron atoms triggered (at least in part) the development of quantum mechanics. Indeed, once the basic formalism had been established by Werner Heisenberg (1902–1976) and Erwin Schrodinger (1887–1961), early variational calculations produced remarkably good results for the ground state of the helium atom, thus opening the way to a wide acceptance of quantum mechanics. In this paper we present several, related, unpublished results obtained almost simultaneously by Ettore Majorana (1906–1938?), which were derived by resorting to novel methods not yet appeared in the literature.

Key words: Majorana, Helium atom, Variational Method, One–and Two–Electron Atoms

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## 1 A Short Introduction

The early wide acceptance of quantum mechanics was triggered by the successful description of the simplest atomic system, i.e. the hydrogen atom, according to well known spectroscopic data. This is usually inferred from the fact that the analytic solution for the wavefunction of the (isolated) hydrogen atom indeed played a pivotal role in subsequent applications of the new quantum theory, during the early part of the XX century. However, the consideration of the helium atom problem, and especially the prediction of the ground state energy of neutral helium, led to the definitive abandonment of the old quantum theory by Niels Bohr (1885–1962) and Arnold Sommerfeld (1868–1851) and opened the door to the development of quantum mechanics in 1920s (Mehra and Rechenberg 1982). Once the basic formalism had been established by W. Heisenberg and E. Schrodinger, early variational calculations (the three–body problem couldn't be exactly solved) provided remarkably good results for the ground state of the helium atom, thus contributing to the general acceptance of quantum mechanics. Within the quantum mechanical framework, atoms with two electrons are described by a wavefunction $\psi$ satisfying the Schrodinger equation (in electronic units):

$$H\psi \equiv -\nabla^2\psi + 2\left( -\frac{Z}{r_1} - \frac{Z}{r_2} + \frac{1}{r_{12}} \right)\psi = W\psi \tag{1}$$

where $r_1$, $r_2$ are the distances of the first and second electron from the nucleus, $r_{12}$ their mutual separation and $W$ the energy of the system in Rydberg. This differential equation is not separable; as a consequence, the eigenfunctions and the energy eigenvalues cannot be expressed in closed analytical form and one has to resort to approximation methods. So the crucial point where different strategies could be developed and tested was the prediction about the ground state energy, mainly for the neutral helium atom (Bethe and Salpeter 2008). Among the different strategies devised in late 1920s–early 1930s to deal with such an issue we remember perturbation theory (Unsold 1927), Ritz variational method (Kellner 1927), Hartree's Self–Consistent Field method (Hartree 1928) and Hylleraas variables (Hylleraas 1928, 1929). In this contribution we present some unknown results on helium atom obtained almost simultaneously by the Italian physicist Ettore Majorana (Esposito 2008), which were derived by resorting to novel methods not yet appeared in the literature (Esposito and Naddeo 2012).

## 2 Majorana's Contribution: Methods and Results

Majorana dealt with helium in his second (Majorana 1931a) and third paper (Majorana 1931b) published in 1931, but both papers discuss subsequent applications of the helium atom, not directly related to what considered here. In particular, in the first one he considered the problem of the chemical bond applied to the study of the molecular ion $He_2^+$ while in the second one he performed the calculation of certain double excited levels of helium within a variational perturbative approach. In his work Majorana used to relate theoretical calculations to experimental observations in order to find appropriate approximations and then check the corresponding accuracy; this attitude is well exploited in the case of helium. In the following we present several interesting results and methods contained in Majorana's unpublished research notes (Esposito 2008) dating back to 1928–1929 and directly related to the two–electron problem.

### 2.1 Variational Method: a Variant

An interesting modification of the variational method by Majorana runs as follows (Esposito 2008). Let us consider an arbitrary function φ in terms of which the wavefunction of the ground state is written as:

$$\psi = a_0 \varphi + a_1 H \varphi \tag{2}$$

$H$ being the Hamiltonian operator. The two variational parameters $a_0$, $a_1$ have to be determined (for a given φ) by minimizing the energy functional:

$$W = \frac{a_0^2 A_1 + 2a_0 a_1 A_2 + a_1^2 A_3}{a_0^2 + 2a_0 a_1 A_1 + a_1^2 A_2} \tag{3}$$

with:

$$A_n = \frac{\int \varphi^* H^n \varphi d\tau}{\int \varphi^* \varphi d\tau} \tag{4}$$

($n$=1,2,3). By introducing the function

$$f(a_0, a_1) = a_0^2 A_1 + 2a_0 a_1 A_2 + a_1^2 A_3 = Wa_0^2 + 2Wa_0 a_1 A_1 + Wa_1^2 A_2 \ ,$$

from the minimizing conditions $\partial f/\partial a_0=0$, $\partial f/\partial a_1=0$ the following set of equations is obtained:

$$\begin{aligned} a_0(A_1 - W) + a_1(A_2 - WA_1) = 0, \\ a_0(A_2 - WA_1) + a_1(A_3 - WA_2) = 0. \end{aligned} \tag{5}$$

It admits non trivial solutions for $a_0$, $a_1$ only by requiring the matrix of coefficients to have a vanishing determinant; such a condition allows one to get the energy $W$ as the smallest root of the corresponding equation, i.e.:

$$W = \frac{A_3 - A_1 A_2 + \sqrt{(A_3 - A_1 A_2)^2 - 4(A_1 A_3 - A_2^2)(A_2 - A_1^2)}}{2(A_2 - A_1^2)} \tag{6}$$

In the *Quaderni*, Majorana did not apply such a method to make numerical predictions about the ground state energy of helium, but here it could be interesting to compare such predictions with known results. For example, by choosing $\varphi = e^{-k(r_1 + r_2)}$, we obtain $W_I$=21.62 eV (for $k$=1.6711), which is not a good result if compared with the result $W_I$=22.95 eV just obtained by Majorana applying the standard variational method with the same trial wavefunction. Probably this consideration led Majorana to further generalize his method by writing the wavefunction as:

$$\psi = a_0 \varphi + a_1 H \varphi + a_2 H^2 \varphi + ... + a_n H^n \varphi \tag{7}$$

for a given $\varphi$ and a general index $n$, and minimizing the corresponding energy:

$$W = \frac{\sum_{i,k=0}^{n} a_i a_k A_{i+k+1}}{\sum_{i,k=0}^{n} a_i a_k A_{i+k}}. \tag{8}$$

By increasing $n$ the calculations give better and better results but become more and more difficult but Majorana focuses, in his notes, on the emergence of divergences. Often, this procedure does not converge, because, starting from a given value of $n$, quantity $H^n\varphi$ exhibits too many singularities, which forces us to consider only combinations of the form

$$\psi = a_0\varphi + a_1 H\varphi + a_2 H^2\varphi + \ldots + a_{n-1}H^{n-1}\varphi \tag{9}$$

The inclusion of additional terms is not useful, since the corresponding $a$ coefficients would necessarily vanish. Here he refers to the calculations of integrals for $r_1$=0, $r_2$=0 or $r_{12}$=0, whose degree of divergency increases upon increasing $n$ in $H^n$, given the form of the Hamiltonian operator.

## 2.2 Various Helium Wavefunctions

The results by Slater (Slater 1928a) about the form of the unperturbed wavefunction and the role played by the operator $H$ within the perturbative method were likely analyzed by Majorana. Indeed he proposed several different forms for the helium wavefunction by realizing what later employed by Hylleraas: the helium wavefunction depends only on three metrics quantities: $r_1$, $r_2$, $r_{12}$. Probably inspired by Slater (Slater 1928b) he firstly introduced the following general wavefunction:

$$\psi = e^{-p},$$
$$p = \frac{2r_1 + 2r_2 - \frac{1}{2}r_{12} + a\left(r_1^2 + r_2^2\right) + br_1r_2 + cr_{12}^2 + d\left(r_1 + r_2\right)r_{12}}{1 + e\left(r_1 + r_2\right) + fr_{12}} \tag{10}$$

where *a*, *b*, ..., *f* are numerical coefficients. The corresponding energy eigenvalue equation was

$$L\psi = \lambda\psi \tag{11}$$

with $L = \frac{4}{r_1} + \frac{4}{r_2} - \frac{2}{r_{12}} + \nabla^2$. Majorana soon realized that calculations would become quite difficult with such a general form and switched to the simpler one

$$\psi_0 = e^{-2r_1 - 2r_2 + \frac{1}{2}r_{12}}. \tag{12}$$

By substituting in the Eq. 11 he got

$$\lambda = \frac{17}{2} - 2\cos\alpha_1 - 2\cos\alpha_2 \tag{13}$$

where $\alpha_1$ [$\alpha_2$] is the angle between $r_1$ [$r_2$] and $r_{12}$. By allowing the cosines to vary in their domain he found the range inside which the energy eigenvalue has to lie: $4.5 \leq -W/Rh \leq 8.5$, a very broad range if compared with the value 5.807 obtained by Hylleraas. Thus Majorana passed to consider the following wavefunction

$$\psi = \left(1 + \frac{1}{2}r_{12}\right)e^{-2r_1 - 2r_2} \tag{14}$$

which approximates those in Eq. 10 and 12 for small $\mathbf{r}_{12}$, i.e. when the two electrons are close each other. Analogous calculations as above led Majorana to the range $3 \leq -W/Rh \leq 8$ for the energy eigenvalue. But he didn't limit to just these wavefunctions and went on to propose several different forms in order to improve the results (Esposito 2008, Esposito and Naddeo 2012). Let us just mention a simpler alternative to Hylleraas' method which generalizes the proposal $\varphi = e^{-k(r_1 + r_2)}$:

$$\psi = e^{-kr_1 - kr_2 + lr_{12}} \tag{15}$$

with arbitrary $k$ and $l$ to be determined. The minimization procedure of the energy functional at first order gives the result $W_I$=24.09 eV (corresponding to $k$=1.8581 and $l$=0.2547) which is extremely accurate if compared with the analogous one produced by Kellner at fourth order, $W_I$=23.75 eV, and even with that obtained by Hylleraas at order 11, $W_I$=24.35 eV.

## 3 Conclusion

Summarizing, the early history of quantum mechanics was strictly related to the successful description of the helium atom with particular reference to the prediction of its ground state energy. In this context we have analysed a number of unknown Majorana contributions whose relevance in current researches in quantum physics is yet to be fully discovered and exploited. These results add new relevant pieces to the history of early quantum mechanics in a field where precision calculations of the electronic structure of the humble helium atom is a vibrant enterprise still today.

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# The Structures of Spacetime Geometry

**Mauro Francaviglia and Lorenzo Fatibene**

**Abstract.** We shall here review some of the insights about the structures of geometry of spacetime implied by gravitational physics. In the early 70s Jürgen Ehlers (1929–2008), Felix A. E. Pirani and Alfred Schild (1921–1977) proposed an interpretational framework for relativistic theories, which suggests to revise the structure of gravitational theories. We shall review a proposal for classifying extended theories of gravitation and consider some examples and applications.

Key words: Geometry of spacetime, Extended theories of gravitation

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## 1 Introduction

General Relativity (GR) has obtained substantial successes in describing the Physics of gravity at Earth, astrophysical and cosmological scales. It has proven to be better than Newtonian gravity in describing the Solar System. More than that, there is no difference in the Solar System tests between what is observed and what is predicted by standard GR. A global positioning system (GPS) was recently set around the Earth which is using standard GR corrections to Newtonian Physics. It is now clear that the GPS system simply would not work without GR corrections and that it would be better to conceive a completely relativistic GPS which does not rest on Newtonian (wrong) assumptions. Besides its success within the Solar System, standard GR has been used to describe the universe at galactic, extragalactic and cosmological scales. The agreement between theory and observations is magnificent at astrophysical scales. Stellar models, neutron stars, binary systems are perfectly described by the theoretical models and observations fully confirm the theoretical predictions. The theory also predicted exotic astrophysical objects such as back holes which are now considered to be observed at astrophysical scales and most galaxies (and Milky Way is no exception) are believed to hide a galactic black hole in their centre. Standard GR has been also used to study models for galaxies, clusters and the universe as a whole. At these scales the agreement between theoretical models and observations begins to be shaken from its foundations.

The first hint came, in fact, from galaxies. Peripheral stars rotate around the galactic centre with a period which is related (actually which defines) the gravitational mass of the galaxy. One can infer the (order of the) mass of the galaxy by measuring its luminosity and find that the observed mass of the galaxy is less than the gravitational mass expected by observing the star orbits (Capozziello and Francaviglia 2008). This situation is usually considered as an evidence that some amount of matter is there without being detected in the luminosity budget. Once this dark halo is added the luminosity profile of a galaxy and its gravitational profile become essentially uncorrelated. Hence one can fit observations.

The dark sources are in fact dark since they escape the luminosity budget, but also because we do not know what they are made of from a fundamental Particle Physics viewpoint. There is no candidate (except from neutrino components) for such matter sources in the so–called Standard Model nor in the new Physics explored by colliders.

The current picture that emerged from astrophysical and cosmological surveys data is quite awkward. In order to fit observations and maintain standard GR as general framework for gravity one is forced to introduce dark sources (Komatsu et al. 2009). Actually, one is led to assume that about 70% of gravitational sources in the universe is constituted by some strange kind of dark energy, closely resembling a (small and positive) cosmological constant, about 30% of gravitational sources is constituted by some kind of dark matter (for which different models have been proposed and discussed), while visible matter amounts to few percents (about 4–5% depending on the model) of the total amount of matter.

In view of these evidences the situation with gravitational physics is quite peculiar. Standard GR has been more or less directly tested in many situations and it requires dark sources, essentially for galactic dynamics and cosmology. Strangely enough galactic and cosmological models rely on solutions of standard GR which are non–vacuum solutions. Also one should consider that to be best of our knowledge all precision tests of GR, which are so successfully passed, are based on vacuum solutions of Einstein equations. For example, Solar System tests rely on the Schwarzschild solution to describe the gravitational field around the Sun.
It is then natural to suspect that dark sources could be interpreted as a hint towards non–standard gravitational physics within matter (i.e., in non–vacuum solutions) at least equally well as a hint of new particle Physics which goes beyond the Standard Model itself.

It is important to notice that we do not have any direct evidence or data about dark energy and dark matter other than their supposed gravitational effects on visible matter. On the contrary, the *Fermi survey*, which was designed also with the aim of detecting gamma rays which could be produced by annihilation of dark matter constituents, until now has ruled out many proposed models for dark matter and found no signal which clearly points to dark matter sources (Fermi–LAT Coll. 2010). Also in view of these considerations, it has been suggested that the description of the gravitational field given by standard GR may fail at cosmological scale and we missed something, so that a good agreement with data can be obtained by modifying the description of gravity rather than adding exotic sources.

In any event it is now clear that something has to be changed in our standard framework in order to understand the universe out there. It is also obvious that we have to be carefully conservative to maintain the successes of standard GR in classical tests.

Originally, Einstein had not many options, since at that time the only way to describe curvature was through a metric structure and general (linear) connections were still to be fully described. As a consequence it becomes very difficult to keep the two things separated as they should.

In the 70s Jürgen Ehlers (1929–2008), Pirani and Schild (EPS) gave a fundamental contribution to the understanding of the foundations of any reasonable theory of spacetime and gravity (Ehlers, Pirani and Schild 1972; Di Mauro, Fatibene, Ferraris and Francaviglia 2010). They proposed an axiomatic approach to gravitational theories which, instead of assuming a metric or a connection on spacetime, assumed potentially observable quantities (namely the world–lines of particles and light rays) as fundamental and derived from them the geometry of spacetime. Their original project was to obtain standard GR. However, EPS framework allows a more general geometric structure on spacetime, in which standard GR comes out to be just one of many possible theories of gravitation that fit the EPS scheme. Moreover, a more general framework potentially allows to test which geometric structure on spacetime is actually physically realised.

We shall hereafter review the EPS framework, define extended theories of gravitation and attempt a rough classification of possible extended theories.

## 2 EPS Structures on Spacetime

In the early 70s Ehlers–Pirani–Schild (EPS) proposed an axiomatic approach to gravitational physics. They decided to start from potentially observable quantities, namely the families of worldlines of massive particles and light rays, and define from them the geometry of spacetime. Of course, they assumed (physically reasonable and well motivated in the classical regime) properties of these families and their mutual relation.

The final output is that geometry on spacetime M is described by a conformal structure, i.e. a class $C = [g]$ of Lorentzian metrics which are conformally related, i.e. $C = [g] = \{g' = \Phi(x)\, g\}$, together with a projective structure, i.e. a class $P = [\Gamma]$ of connections which share the same geodesics (or, better, autoparallel) trajectories, namely:

$$P = [\Gamma] = \{(\Gamma')^{\alpha}{}_{\beta\mu} = \Gamma^{\alpha}{}_{\beta\mu} + A_{(\mu}\delta^{\alpha}{}_{\beta)}\} \text{ for some 1–form } A \qquad (1)$$

The conformal structure C can be used to define timelike, lightlike, spacelike directions in spacetime and light cones. The projective structure P defines a congruence of worldlines which, by construction, describe the free fall of massive particles. The conformal and projective structures are EPS–compatible when lightlike geodesics of the conformal structure form a proper subset of geodesics trajectories of the projective structure. The triple (M, C, P) is called an EPS geometry. EPS attempted to further constrain EPS geometry by singling out a metric which represents the conformal structure and the free fall. This can be done by requiring extra properties of world–lines. However, even Ehlers, Pirani, and Schild noticed that these extra assumptions appeared much less certain than the other standard assumptions (Ehlers, Pirani and Schild 1972; Di Mauro, Fatibene, Ferraris and Francaviglia 2010).

Given a pair of compatible conformal and projective structures, one can canonically fix a representative $\Gamma$ of the projective structure P such that for all g one has $\nabla g = 2A \otimes g$ for some 1–form A (that depends on g). This is a sort of canonical and global gauge fixing of the projective structure. If $g'$ is another representative of the conformal structure C then the same connection is singled out by choosing a suitable $A'$ so that the gauge fixing just depends on the conformal structure C and not on a specific representative (Dadhich and Pons 2012). The resulting triple (M, C, $\Gamma$) is called a Weyl geometry. Weyl geometries have been introduced originally to attempt a gauge formulation of the electromagnetic field. In that context, the connection $\Gamma$ is integrable (i.e., it is generated by a metric) if and only is the corresponding electromagnetic field F=dA is vanishing.

Accordingly, integrable Weyl geometries are not very interesting in the original electromagnetic context. In EPS framework, however, a Weyl geometry has no electromagnetic interpretation and it arises as a purely gravitational object. In EPS the 1–form A is not related to the electromagnetic potential, it parametrizes the possible mismatch between light cones geometries and free falling of particles (which is assumed to vanish in standard GR, but not in a generic EPS framework). Then integrable Weyl geometries are a relevant subset to be considered.

Let us remark that the original Weyl electromagnetism was criticized, among other things, since the length of rulers would there depend on the path, depending on the holonomy of $\Gamma$. If the Weyl geometry is restricted to be integrable, the holonomy effect on length of rulers is trivial and these lengths turn out to be well defined.

In view of EPS framework it is natural to use *Palatini formalism* to describe gravity; metric and connection are considered a priori independent and while the metric g is meant to represent light cones through its conformal structure, the connection Γ is meant to determine free falling of particles. Usually, the connection is a priori required to be torsionless (since torsion would not affect in any case the motion of particles) but it is not restricted to be metric, even less to be determined by the metric g. Accordingly, the dynamics is expected to be conformally invariant (and of course conformal transformations are pointwise rescalings of the metric, leaving the connection and the spacetime event fixed) and to force the connection to be EPS–compatible with the conformal structure determined by field equations.

Let us stress the obvious, explicitly: the metric g contains more information than its conformal structure. Everything using a specific metric g does rely on a gauge fixing of the conformal freedom. In particular distances and clock rates depend on such a conformal gauge fixing.

A number of dynamics with these properties are quite well known (Fatibene, Ferraris, Francaviglia and Mercadante 2010). There exists a class of couplings between gravity and matter (more precisely between matter and the connection Γ) which force the connection to be EPS–compatible with the conformal structure determined by g. The relativistic theories where this happens are called extended theories of gravitation (ETG). In such theories the connection is not even constrained to be metric, with all problems of holonomic nature which are well known (e.g., the length of a ruler depends on its path!). EPS however provides a framework for the interpretation of gravitational theories and for discussing observability of gravitational field in terms of the motion of particles and light rays.

A subclass of ETG are metric extended theories of gravitation (mETG) in which dynamics does not only constrain the connection to be EPS–compatible, but also to be metric, i.e. Γ is a posteriori forced to be the Levi–Civita connection of some metric related to g (but not necessarily equal to g). In these models there are no holonomy interpretation problems and, in a sense, there exists a single metric g determining both light cones and free fall. These models correspond to the 1–form A determined to be exact and they include all the so–called f(R)–theories in which the Lagrangian is assumed to be an analytic (or sufficiently regular) function of the scalar curvature $R = g^{\mu\nu}R_{\mu\nu}$ which depends both on the metric g and the connection Γ through its Ricci tensor $R_{\mu\nu}$.

We have to stress that choosing standard GR as the only possible model within a quite wide class of mETG (or maybe even ETG) is not really reasonable even if it were eventually true. The point here is that one should not assume standard GR to be the theory, but, following Riemann:

> The curvature of space has to be determined on the bases of astronomical observations.[1]

The theory has to be decided on the bases of observations. In order to project experiments which could address the issue, one would in any event need a wider interpretational framework for gravitational physics. EPS provides such a framework. Moreover, recently f(R)–theories have been shown to be able to describe observational data from cosmology and astrophysics. Palatini f(R)–theories in fact have a peculiar feature which is known as universality theorem (Borowiec, Ferraris, Francaviglia and Volovich 1998).

If one restricts to vacuum (or purely electromagnetic) solutions, any Palatini f(R)–theories turns out to be a posteriori equivalent to Einstein GR with a cosmological constant $\Lambda$ the value of which is forced to belong to a set which is in turn determined by the function f chosen as a Lagrangian for the theory. Since we know, also from local tests, that the value of the cosmological constant has to be rather small, then the behavior of the function f(R) is constrained around the origin R =0. Still there is a whole family of models which agree with local observations in vacuum gravity.

In view of this equivalence it can be rather hard to distinguish between f(R)–theories and standard GR (with a cosmological constant) in vacuum or with purely electromagnetic solutions. When matter is added, still f(R)–theories can be written as an almost standard field equations (Einstein–equations–like field equations, though for a conformal metric $g'$ and a conformal factor which is again dictated by the function f(R), where the scalar curvature R turns out to be now a function of the matter energy stress tensor).The effect of f(R)–theories naturally recasts as a standard GR theory, though with a modified source term (which vanishes in vacuum and purely electromagnetic solutions). There is a hope (and some evidences) that the function f(R) can be chosen so that the modification induced on sources term accounts for dark sources without introducing exotic particles.

In cosmological scenarios it is natural to expect the density of (visible) matter to be a function of time (through the density of the FRW fluid). In these scenarios the conformal factor involved in the definition of the

[1] Riemann 1854, p 11.

metric $g'$ (for which almost standard GR dynamics is recovered) is naturally expected to be a function of time. Since the metric defines length and time lapses, one could also argue that quite naturally one could expect effects due to redefinition of units of length and times (and consequently of masses, since masses in astronomy are defined by third Kepler's law and thence get a dependence on conformal transformations) which could affect differently observations at different ages of the universe.

In order to confirm such expectations one should scrutinise in detail the observational protocols and operational definitions of length and time lapses and confirm whether they depend or not on the conformal gauges.
There are a number of evidences for that; still an ultimate evidence is still missing, as it is missing a conclusive evidence that such redefinition of units are strongly constrained by observational data. Far from being a defect, the possibility of ruling out in principle by observation the modified dynamics of f(R)–theories is the proof that the framework is effective to test assumptions of standard GR on observational ground.

## 3 Conclusion

If Special Relativity is a theory for empty space (or at most for empty space and electromagnetism) the gravitational field is related to curvature effects. As long as one adds matter, that matter generates a gravitational field which is to be described in terms of the curvature of some geometric structure on spacetime.

EPS framework and Weyl geometries leave space for the connection to contain more information than the metric field. Accordingly, the curvature which describes the gravitational field can be more general than the standard metric curvature. In Weyl geometries there are extra degrees of freedom (that in f(R)–theories reduce to a single conformal factor which is described by a scalar field). The metric structure is related to light cones while the connection is related to free fall and it is natural to describe the gravitational field in terms of the connection (which in fact determines the free fall). Gravity is thence described in terms of the curvature of the connection. The modified dynamics is encoded into extra effective sources which in principle is detectable only through their gravitational effects, as until now is for dark energy and dark matter.

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# Historical Approach to Physics according to Kant, Einstein, and Hegel

**Young Suh Kim**

**Abstract.** It is known that Einstein's conceptual base for his theory of relativity was the philosophy formulated by Immanuel Kant. Things appear differently to observers in different frames. However, Kant's Ding–an–Sich leads to the existence of the absolute reference frame which is not acceptable in Einstein's theory. It is possible to avoid this conflict using the ancient Chinese philosophy of Taoism where two different views can co–exist in harmony. This is not enough to explain Einstein's discovery of the mass–energy relation. The energy–momentum relations for slow and ultra–fast particles take different forms. Einstein was able to synthesize these two formulas to create his energy–mass relation. Indeed, this is what Hegelianism is about in physics. Isaac Newton synthesized open orbits for comets and closed orbits for planets to create his second law of motion. Maxwell combined electricity and magnetism to create his four equations to the present–day wireless world. In order to synthesize wave and particle views of matter, Heisenberg formulated his uncertainty principle. Relativity and quantum mechanics are the two greatest theories formulated in the 20th Century. Efforts to synthesize these two theories are discussed in detail.

Key words: Dirac, Einstein, Hadons, Hegel, History of Physics, Kant, Lorentz covariance, Quantum mechanics, Relativity, Taoism

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## 1 Introduction

Einstein studied the philosophy of Immanuel Kant during his earlier years. It is thus not difficult to see he was influenced by Kantian view of the world when he formulated his special theory of relativity. It is also known that, in formulating his philosophy, Kant was heavily influenced by the environment of Koenigsberg where he spent eighty years of entire life. The first question is what aspect of Kant's city was influential to Kant. We shall start with this issue in this report.

In Einstein's theory, one object looks differently to moving observers with different speeds. This aspect is quite consistent with Kant's philosophy. According to him, one given object or event can appear differently to observers in different environments or with different mindsets. In order to resolve this issue, Kant had to introduce the concept of "Ding–an–Sich" or thing in itself meaning an ultimate object of absolute truth. Indeed, Kant had a concept of relativity as Einstein did, but his Ding–an–Sich led to the absolute frame of reference. Here Kantianism breaks down in Einstein's theory. Kant's absolute frame does not exist according to Einstein. In order to resolve this issue, let us go to the ancient Chinese philosophy of Taoism. Here, there are two different observers with two opposite points of view. However, this world works when these two views form a harmony. Indeed, Einsteinism is more consistent with Taoism. The energy–momentum relations is different for a massive–slow particle and for a fast–massless particle. Einstein's relativity achieved the harmony between these two formulas. This leads us to Hegel's approach to the world. If there are two opposite things, it is possible to derive a new thing from them. This is what Einsteinism is all about. Einstein derived his $E = mc^2$ from two different expressions of the energy–momentum relation for massive and mass–less particles. Einstein thus started with Kantianism, but he developed a Hegelian approach to physical problems. Indeed, this encourages us to see how this Hegelianism played the role in developing new laws of physics. For instance, Newton's equation of motion combines the open orbits for comets and the closed orbits of planets. If this Hegelian approach is so natural to the history of physics, there is a good reason.

Hegel derived his philosophy by studying history. Hegel observed that Christianity is a product of Jewish one–God religion and Greek philosophy. Since Hegel did not understand physics, his reasoning was based on historical development of human relations. It is thus interesting proposition to interpret Hegel's philosophy using the precise science of Physics. In Secs. 2 and 3, we review how Kantianism was developed and how Einstein was influenced by Kant. In Sec. 4, it is pointed out that Hegelianism is the natural language in understanding physics. In Sec. 5, we examine whether quantum mechanics and relativity can be combined into one theory according to Hegelian approach to the history of physics.

## 2 Geographic Origin of Kantianism and Taoism

Immanuel Kant (1724–1804) was born in the East Prussian city of Koenigsberg, and there he spent 80 years of his entire life. It is agreed that his philosophy was influenced by the lifestyle of Koenigsberg. The city of Koenigberg (now Kaliningrad) is located at the Baltic wedge between Poland and Lithuania. It is also between two large lagoons.. This place served as the traffic enter for maritime traders in the Baltic Sea. In addition, this city is between the eastern and western worlds (Applebaum 1994). However, there are no natural boundaries such as rivers or mountains. Thus, anyone with a stronger army could come to this area and run the place. Indeed, Koenigsberg was a meeting place for many people with different ideas and different viewpoints. Kant observed that the same thing can appear differently depending on the observer's location or state of mind. The basic ingredients of Taoism are known to be two opposite elements Yang (plus) and Ying (minus). This world works best if these two elements form a harmony. However, the most interesting aspect of Taoism is that its geographic origin is the same as that of Kantianism.

After the ice age, China started as collection of isolated pockets of population. They then came to banks of the Yellow River, and started to communicate with those from other areas. They drew pictures for written communication leading eventually to Chinese characters. How about different ideas? They grouped many different opinions into two groups, leading to the concept of Yang and Ying. Immanuel Kant considered many different views, but he concluded that there must be one and only truth.

Indeed, Taoism and Kantianism started with the same environment, but Kant insisted on one truth called Ding–an–Sich, while Taoism ended up with two opposing elements (Kim 2006). It is however interesting to note that both Kantianism and Taoism were developed from the same geographical condition, namely different people coming to one place.

## 3 Kantian Influence on Einstein

During his early years, Einstein became quite interested in Kant and studied his philosophy rigorously. This was quite common among the young students during his time. Einstein however studied also physics, and got an idea that one object could appear differently for observers moving with different speeds. Let us go to Fig. 1. According Kant, an object or event look differently to different observers depending on their places or states of mind. A Coca–Cola can looks like a circle if viewed from the top. It appears like a rectangle if viewed from the side. The Coca–Cola can is an absolute thing or his Ding–an–Sich. Likewise, the electron orbit of the hydrogen atom looks like a circle for an observer when both the hydrogen and the observer are stationary. If the hydrogen atom in on a train, our first guess is that it should look like an ellipse. This is what Einstein inherited from Kant.

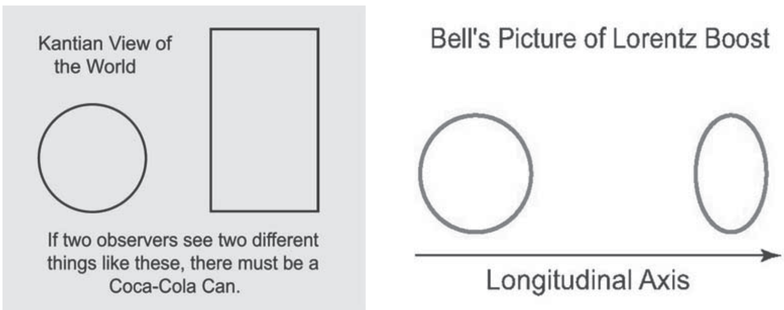



**Fig. 1** A Coca–Cola can appear differently to two observers from two different angles.[1]

[1] Likewise, the electron orbit in the hydrogen atom should appear differently to two observers moving with two different speeds.

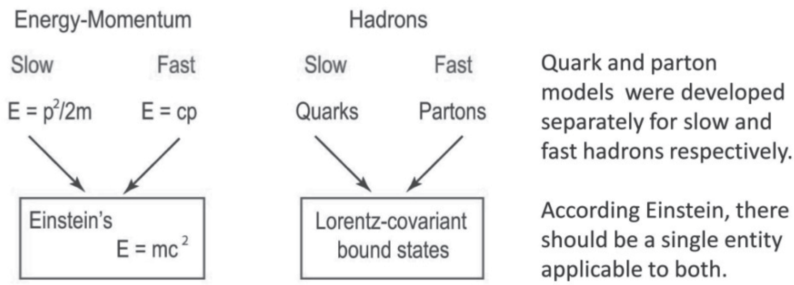


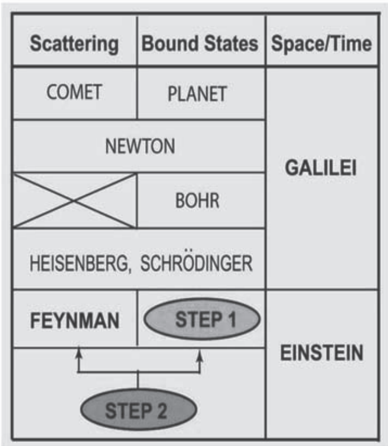

**Fig. 2** The energy–momentum relation of a particle takes different form when the particle moves with different speeds.[2]

However, does the hydrogen atom require a Ding–an–Sich? The answer is No. Indeed, Kant attempted to formulate his theory of relativity with an absolute coordinate system corresponding to his Ding–an–Sich. This is the basic departure of Einsteinism from Kantianism. Let us come back to Einstein. Like Kant, Einstein started from different observers looking at a thing differently, but ended up with a particle at the rest and the same particle moving with a speed close to that of light. He then derived his celebrated energy–mass relation, as indicated in Fig. 2 (left). Einstein had to invent a formula applicable to both. This is precisely a Hegelian approach to physics. It is not clear whether Einstein knew he was doing Hegel. This remains as an interesting historical problem. As for Einstein's hydrogen atom, we now have hadrons which are bound states of quarks, while the hydrogen atom is a bound state of a proton and an electron. The proton is a hadron and is a charged particle which can be accelerated to the speed very close to that of light. We shall return in Sec. 5 to the problem presented in Fig. 2 (right).

[2] Let us choose two limiting cases. Einstein was able to find the same formula applicable to both. In so doing, he found his $E = mc^2$. Likewise, the quark model (Gell–Mann 1964) and the parton model (Feynman 1969) should produce a Lorentz–covariant picture of the bound state.

## 4 Hegelian Approach to the History of Physics

Since Hegel formulated his philosophy while studying history, it is quite natural to write the history of physics according to Hegel. First of all, Isaac Newton combined hyperbolic–like orbits for comets and elliptic orbits for planets to derive his second–order differential equation which is known today as the equation of motion, as is illustrated in Fig. 3 (left).




Humans developed the theories of electricity of magnetism separately. James Clerk Maxwell combined them into one theory, leading to the present form of wireless world. However, the transformation law of his theory is different from that of Newtonian mechanics. This was another challenge to Einstein.

| Tranformation | Newton | Maxwell |
|---|---|---|
| Galilei | Yes | No |
| Lorentz | No | Yes |

**Fig. 3** Progresses of physical theories are made when two theories are combined into one.[3]

James Clerk Maxwell combined the theory of electricity and that for magnetism to formulate his electromagnetic theory leading to the present world of wireless communication. Einstein noted Newton's mechanics and Maxwell's equations obey different transformation laws. He made both to obey the same transformation law, leading to his theory of relativity.
Max Planck observed that the radiation laws are different for low– and high–frequency limits. By deriving one formula for both, he discovered Planck's constant. Werner Heisenberg observed the matter appears as a particle also appears as a wave, with entirely different properties. He found

[3] The left side of this figure shows how mechanics was developed. The right side tells how the mechanics and electromagnetism were led to obey the same transformation law.

the common ground for both. In so doing, he found the uncertainty relation which constitutes the foundation of quantum mechanics. Indeed, quantum mechanics and relativity were two most fundamental theories formulated in the twentieth century. They were developed independently. The question is whether they can be combined into one theory. We shall examine how Hegelian approach is appropriate for this problem in Sec. 5.

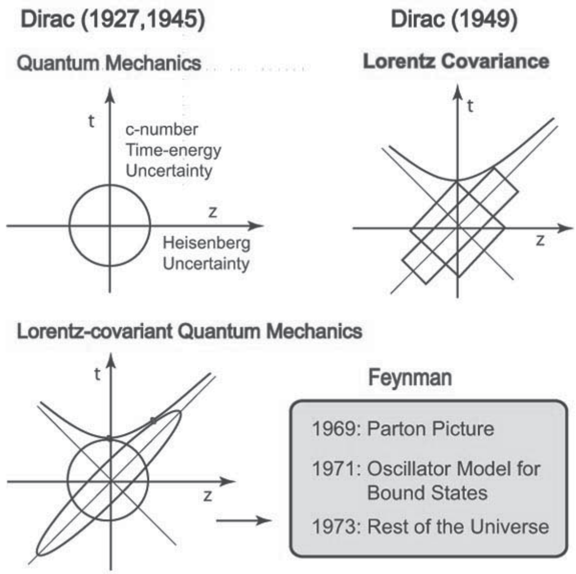



**Fig. 4** Dirac's quantum mechanics (1927) and Dirac's relativity (1949)[4]

## 5 How to combine Quantum Mechanics and Relativity

Here again, the problem becomes divided into scattering and bound state problems. Quantum field theory was developed for scattering problems, and this theory is accepted as a valid theory, as is illustrated in Fig. 4. For

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[4] If they are combined, it leads to a Lorentz–covariant bound–state picture which produces the quark and parton models are two different limiting cases of one formula, just as in the case of Einstein's energy–momentum formula.

bound–state problems, Paul Adrien Maurice Dirac (1902–1984) wrote three important papers on this subject (Dirac 1927, 1945, 1949). His 1927 paper tells us there is a time–energy uncertainty relation. In 1945, he attempted to use the harmonic oscillator to formulate quantum mechanics applicable to Einstein's world. If we combine or Hegelize Dirac's 1927 and 1945 papers, we end up with the circle given in Fig. 4. In 1949, Dirac showed that the Lorentz boost can be described as a squeeze transformation as shown in Fig. 4. If we Hegelize the circle and the squeezed rectangle, we arrive at the ellipse (Kim and Noz 2011) which can explain what happens in the real world including the quark model (Gell–Mann 1964) and the parton model (Feynman 1969). This Hegelian procedure corresponds to Step 1 in Fig. 4. The final step in constructing Lorentz–covariant quantum mechanics is to show that the scattering and bound states share the same set of fundamental principles (Han *et al.* 1981). This Hegelians procedure is illustrated in as Step 2 in Fig. 3 (left).

## 6 Conclusion. Kant, Hegel, and Einstein

Kant and Hegel are two of the most fundamental thinkers affecting our present–day lifestyle. However, their philosophies were based largely on social events and applicable to formulation of social sciences. It is gratifying to note that Einstein gives us a more concrete picture of their approaches to the problems. By building the bridge between Kant and Hegel, Einstein not only gives us the precise description of how physical theories were developed in the past but also tells us how to approach current problems in physics.

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# The Concept of Work in the Development of Applied Mechanics: Carnot and Coriolis

**Agamenon Rodrigues Eufrásio Oliveira**

**Abstract.** In this paper, we are mainly concerned with the contributions of French engineers, mainly Lazare Carnot (1753–1823) general theory of machines, and Gaspard–Gustave de Coriolis (1792–1843) who wrote the first textbook on applied mechanics: *Du calcul de l'effet des machines* (1829). These two books have in common the use of the concept of work as a fundamental step to build a general theory of applied mechanics within the framework of Rational Mechanics. Carnot started to develop his theory of machines applying d'Alembert (1717–1783) principle. Coriolis, in his book, develops Lazare Carnot's project and uses extensively the concept of work associated to the new mathematical formalism.

Key words: History of work, History of applied mechanics, Carnot, Coriolis

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## 1 A Short Introduction

The first author to refer Carnot's work appears in the first decades of XIX$^{th}$ century. He was André Guenyveau (1782–1861), who in 1810 published the *Essai sur la science des machines* (Guenyveau 1810) different of Carnot's memories (Carnot L 1778, 1780). He studied the equilibrium of machines and presented a series of practical applications, using the Coulomb's memoir in which machines motion can appear by means of shock or pressure. This distinction also indicates that continuous transmissions provide the best efficiency. Nevertheless, Guenyveau do not attributes to Carnot the origin of the principle of living forces used, in spite that in the preface of his *Essay* Carnot is referred as the author that develops a general treatise on machines.

Other author who cites Carnot is Jean–Nicolas–Pierre Hachette (1769–1834). He referrers Carnot's *Principes fondamentaux de équilibre et du mouvement* (Carnot L 1803) appearing in the preface of his *Traité élémentaire des machines* (Hachette 1811). Hachette remarks that Carnot in the last chapter of his *Principes fondamentaux de équilibre et du mouvement* studies the whole theory of machines and the moving applied forces. In addition he mentions Carnot as *the most profound savant and experienced engineer*. Paradoxally, Hachette uses few Carnot's achievements. In fact the course taught by him is much more a collection of drawings of particular machines, studying also machines elements as gears, pulleys, etc.

Alexis Petit (1791–1820) develops an investigation in the same sense that conducts to application of work concept. In 1818 he published *Sur l'emploi du principe des forces–vives dans le calcul de l'effet des machines* (Petit 1818) which is a very interesting work and coincides with our line of investigation. Petit was a physician who together with Pierre Dulong (1785–1838) postulated a law with his names and died prematurely. He presented general properties of motion as the conservation of living forces sponsored by him as being the most efficient approach to machines calculation. According to him is the living force concept that permits in each particular case the best natural evaluation of the motor action and the effect produced. The equation expressing the relation between these two quantities can provides the direct solution to the machine problem. In fact what Petit was proposing is a method of energy balance to solve this problem.

## 2 Notes on Lazare Carnot's *Mémoires sur la théorie des machines* (1778, 1780)

Before the appearing of his *Principes fondamentaux de équilibre et du mouvement* in 1803, Carnot wrote two introductory studies known as *Mémoire sur la théorie des machines* in the 1778 and 1780, respectively (Carnot L 1778, 1780; see also Coulomb 2002). The fundamental assumption to the development of an applied mechanics theory is that these two *Essays* were preliminary studies to his masterpiece. As we are focusing our attention to a general theory of machines instead of a general analysis on Carnot's mechanics (Gillispie and Pisano 2013; Gillispie 1971, 1979; Charnay 1990) only the aspects directly associated to this theory are considered here.

### 2.1 *Carnot's Principes fondamentaux de équilibre et du mouvement* (1803)

The *Principes fondamentaux de équilibre et du mouvement* was published in Paris in 1803 by Deterville, which was written in 262 pages. Starting from page 227, paragraph 252, Carnot treats directly the questions related to machines. It is the final part of *Principes fondamentaux* where the same subtitle is maintained, in which he studies the problems arisen from machines operation. The sequence followed by him starts with machines in equilibrium, followed by motion analysis, and the forms to increase machines efficiency. Obviously these are problems emerged from the needs of industry and engineering at that moment. The polythecnicians–engineers of the first decades of XIX$^{th}$ century since the publication of *Principes fondamentaux* will develop new concepts and a new theory of machines. It is important to stress again the role of the concept of work to these developments. As we will see, this concept occupies a central position in the majority of the investigations of this period.

Lazare Carnot starts by defining a machine as a body or a system of bodies which are in–between two or more powers (*forces*), with the condition to fulfill a given objective. He emphasizes that, in general, these bodies are considered without mass because its small effect with the applied system of forces, independently if these forces are driven or inertia forces. He states that this abstraction simplifies the problem. At this beginning Carnot also discusses questions of modeling a machine by the use of a convenient representation with a great quantity of corpuscles separated by strings and bars, through which motion is transmitted from one element to its neighbors and so on. Carnot is aware of the general character of his investigation and said that his intention is not to search for *particular properties of each machine, what he has remarked before, but to offer some considerations about the machines, and the common properties to every machine*. For the case of motion, not only the weight must be considered, but the height to be elevated, making these two operations with the machine, quite different. For the equilibrium, the machine could centuplicate the force effect while for the machine in motion we have an invariable quantity which is always the product of a force by the path described, estimated in the force sense. In other words, Carnot discusses exactly the question of energy in the field of mechanics, which is expressed by mechanical work. To eliminate any doubt he uses an example of a horse which is two times stronger than another, meaning that it can elevate a new quantity of water, for instance, a double height of the second at the same time, or a double quantity of water for the same height, also to the same time. It is important to say that the definition of mechanical power appears here in this context, in a very simple form.

Carnot studies then the problem of the transformation of work in motion by considering all the parameters involved. From this viewpoint it means to establish convenient variations of the terms of the quantity *FVT*, i. e., the moment of activity, later on denominated of work by Coriolis, as we will see in the next item. Thus, if time is the most important parameter and we should minimize it, the effect must be produced in a very short time. It is possible to generalize these reasoning for the case of a system of forces, for instance; if we have the forces *F, F', F''* with the velocities *V, V', V'',* acting during the times *T, T', T'',* respectively, then one reads:

$$FVT = F'V'T' = F''V''T'' = PH \tag{1}$$

If the motion of each one of the forces is variable, we will take the quantity:

$$\int \left( FVT = F'V'T' = F''V''T'' \right),$$

or if we have the forces directions with respect to velocities, one has:

$$\int FVdt\cos\left(F^\wedge V\right) + F'V'dt'\cos\left(F'^\wedge V'\right) + F''V''dt''\cos\left(F''^\wedge V''\right) \tag{2}$$

This is the definition of work done by all forces. The quantity *PH*, the effect to be produced by machine, is, by Carnot called latent living force.
If we call *M* the mass of the weight *P*, and *V* the velocity correspondent to a height H, one reads:

$$PH = \frac{1}{2}MV^2 \tag{3}$$

## 3 Notes on Coriolis' *Du calcul de l'effet des machines* (1829)

The most important work in the sense of a transition to a TMM (Theory of Machines and Mechanisms) came up with Gaspard–Gustave de Coriolis (1792–1843). The approach given by him differs substantially from the usual Newtonian mechanics method used in XVIII$^{th}$ century and is also quite different from the general mechanics of the XIX$^{th}$ century. Because all of these characteristics the Coriolis' textbook *Du calcul de l'effet des machines* (Coriolis 1829; see also 1832) is a remarkable advancement to an applied mechanics since the publication of Carnot'*s Principes fondamentaux de l'equilibre et du mouvement* in 1803.In this book he corrected the expression for kinetic energy introducing the constant ½ in the old expression mv$^2$ and adopted the term *work* to represent the product of a force by its displacement along the force trajectory replacing the previous nomenclature. In fact, a rigorous analysis shows that the new term was adopted by the new generation of polytechnics engineers. In addition Coriolis suggested a new unity to work as *dynamode* but it was not adopted. The term *dynamode* is a composition of two words, *dynamis* meaning power and *hodos* to designate trajectory; 1 *dynamode* is equal to 1000 kg.m.

### 3.1 *Coriolis' Textbook*

Coriolis' textbook (Coriolis 1829) is the result of writings accumulated since 1819. His main objective was to develop the Lazare Carnot project which created a general theory of machines based on d'Alembert principle but in general as a product of the tradition of Newtonian mechanics. What is new in Coriolis' approach is the extensive use of the concept of work with its mathematical formalism which is quite different from Newtonian concepts. The new approach adopted by him can be better understood if we look at the two general approaches used to solve a given mechanical problem. The first one is to consider the variations of motion as the result of forces, in a Newtonian way. Alternatively, knowing the amount of work generated by the system try to find the *living forces* involved. In other words, we can use Newton's second law or work–kinetic energy principle. Coriolis' new approach to TMM is based in transmission work principle. On the other hand his economic analysis about machine operation is supported by the same concept of economic production used by other polytechnics engineers of his generation. They reduced economic production to a mechanical action against passive forces consisting in force displacements or bodies' deformations. This production obviously is represented by work. Coriolis considers also another concept that is the capacity to accomplish an amount of work which has its limitations in time and that it refers to a given place. Hence, this capacity is merchandise with the same meaning used by economists. In other words, it can be bought, sold or saved likewise a product. He made the distinction between work, not merchandise but the capacity to accomplish it, a merchandise.

## 4 Conclusion

If we compare the famous Coriolis' *Du calcul de l'effet des machines* (1829) with Carnot's *Principes fondamentaux de équilibre et du mouvement* (1803) it is easy to see that it represents a great progress from the technical point of view, as well as by its completeness, style and language. The twenty five years that separates these two fundamental books in the mechanical engineering history does not present important works, except the notes and remarks of Navier about Bélidor. This advancement in mechanical field which means the development of applied mechanics in the industrial progress context is also a remarkable aspect of engineering development. This process had a great influence in engineering education due to the need to prepare the technicians in order to give continuity to the technical progress itself and thus also providing a fundamental requirement to Industrial Revolution at this moment spreading along European continent. As we know, Coriolis was lecturer in Polytechnic School, Navier did the same in School of Bridges and Highways.

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# Early Modern Histories of Astronomy: the Views on the Progress of Astronomy

**Daniel Špelda**

**Abstract.** This paper focuses on the various ways in which astronomers in early modern period viewed the progress of astronomy Some of the Renaissance astronomers and scholars thought that it is necessary to find and restore ancient astronomy which had been given by God to the first humans. Gradually, however, among astronomers and the early historians of mathematical sciences the view prevailed that the true astronomy is not hidden in the past of the human race, but awaits humanity in the future as a result of long–term, international and trans–generational cooperation.

Key words: History of astronomy, Renaissance astronomy, Early modern science, Progress of science

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## 1 An outline of the Problem

Nowadays, we find it natural to see the history of science as a process of continuous, cumulative improvement, in other words, as constant progress. In the sixteenth and seventeenth centuries, however, astronomers perceived the history of their science differently. They believed that before the great flood, at the dawn of human history, there existed a perfect, fully developed astronomy. This conception I shall call retrograde. Only in the eighteenth century, the notion that astronomical knowledge improves with the progress of time found a definite, firm footing. This view I shall call progressivist. In the following, I want to outline some basic features of the complex methodological change resulting in the emergence of the idea of astronomical progress at the beginning of 18$^{th}$ century.

## 2 The Story of Flavius

In their ideas about the origins of astronomy, the Renaissance astronomers (some of them are quoted bellow) usually drew on the reports of various classical Greek and Roman authors, such as Plutarch, Diodorus Siculus or Pliny.[1] By far most influential was the story presented by Josephus Flavius, a Jewish historian who lived in the first century (37–c. 100). From several passages in Flavius' main historical treatise *Jewish Antiquities*, one can reconstruct a narrative about the origins and early history of astronomy. It contains three important ideas. Flavius writes that after the expulsion from the Garden of Eden, Adam had many descendants:

> [T]hey also discovered the science of the heavenly bodies and their orderly array. Moreover, to prevent their discoveries from being lost to mankind and perishing before they became known – Adam having predicted a destruction of the universe, at one time by a violent fire and at another by a mighty deluge of water – they erected two pillars, one of brick and the other of stone, and inscribed these discoveries on both; so that, if the pillar of brick disappeared in the deluge, that of stone would remain to teach men what was graven thereon and to inform them that

[1] Very useful overview of the Greek theories of the origins and history of science was presented by Leonid Zhmud (Zhmud 2006, pp 228–75).

> they had also erected one of brick. It exists to this day in the land of Seiris.[2]

Elsewhere, Flavius explains longevity of the biblical patriarchs: They were loved by God and they had special eating habits. Apart from that, God gave the patriarchs long lives so as to afford them enough time to learn the movements of celestial bodies, since if they had not lived for at least six hundred years, they would not have been able to gain this knowledge (Flavius 1961, p 50). Because of mankind's growing depravity, Flavius, writes, God sent a flood on the Earth, which was survived only by Noah and his family. Noah himself was a brilliant astronomer, who passed his knowledge on to his sons who gradually populated the earth. His son Shem especially excelled in astronomy and his descendants came to found the Chaldean nation. According to Flavius, Abraham – who himself came from the Chaldean environment – visited Egypt, where he taught arithmetic and astronomy to Egyptian priests, who were as yet ignorant of these sciences. From Egyptians, astronomical knowledge passed on to the Greeks (and with Greeks starts the history of astronomy as based on textual sources available to Early Modern astronomers) (Flavius 1961, p 82). In this way, Flavius outlined a broadly accepted link between biblical patriarchs, Chaldeans, Abraham, Egyptians, and Greeks.

## 3 Antediluvian Astronomy as a Gift and Ideal

The story presented by Flavius fits well in with the retrograde mentality of Renaissance culture, which inclined to seeking perfection in antiquity. In early modern times, it became a very influential and often quoted explanation of the origin and creation of astronomy. The astronomers used to link the origin of astronomy with Adam and other biblical patriarchs. They emphasised that God himself inspired Adam and gave him astronomy as a gift. And God would certainly want people to use and develop his gift. Such an idea we can find by the Italian scholar Annio of Viterbo (1432–1502) who presented forged and fabricated history of humankind's ancient history (Annio of Viterbo 1545, folio 1r). Similarly, according to the Milano doctor and astrologer Gabriele Pirovano (d. 1512)

[2] Flavius 1961, p 32.

astronomy has been a gift from God (Pirovano 1507, folio B 5r). The Heidelberg professor of mathematics, Hermann Wittekind (1521–1603) speaks about a gift as well (*hoc tantum Dei donum tam utile et necessarium*) (Wittekind 1590, p 9). And the famous Jesuit astronomers, Christopher Clavius (1538–1612) and Giovanni Battista Riccioli (1598–1671), expressed themselves in the same way (Clavius 1611, p 2; Riccioli 1651, p viii; see also Byrne 2006; Grafton 1997; Popper 2006).

The German Protestant astronomers such as Erasmus Reinhold (1511−1553), author of the famous *Tabulae prutenicae*, or Kepler's teacher Michael Mästlin (1550−1631) took this line of thinking even further. They argued that God not only gave astronomy to people at the beginning of their history but He still actively intervenes in human history to prevent astronomical knowledge from being lost. According to the Wittenberg astronomers, the columns erected by Adam's descendants are a proof of divine omniscience, which at the times of the patriarchs – but also later – took care that astronomical learning is not lost but persists through wars and disasters in order to serve mankind (Reinhold 1843, p 820; Reinhold 1551, folio 3rv; Mästlin 1558, folio 3r). Thus, as it turns out the story of Flavius also served astronomers in early modern times as an argument in a theological justification of astronomy. According to this line of reasoning, people owe their knowledge of heavenly bodies to God. Knowledge of the stars is thus not something won from nature but a gift from Heavens which people should accept and develop.

Almost all astronomers who believed in the existence of antediluvian astronomy also thought that after the great deluge and Babylonian confusion of languages, almost no part of that ancient knowledge was preserved. In their view, perhaps only little fragments of antediluvian wisdom survived these cataclysms, and these fragments were used in creating the astronomical theories of Chaldeans and Egyptians, which were later taken up by the Greeks. At the same time, astronomers of the fifteenth and sixteenth century believed that astronomy is in crisis and in need of a thorough reform. Some of them were convinced that Aristotle's cosmology of concentric spheres and Ptolemy's mathematical astronomy with its complicated system of epicycles and excentres are relatively late conceptions which disguise or overlay the more genuine, simpler, and more correct astronomy of earlier civilisations, civilisations which still perhaps had at their disposal remnants of antediluvian knowledge. The notion of ancient or antediluvian astronomy thus started functioning as a sort of abstract ideal of a perfect but lost astronomy. And it was this perfect knowledge that astronomers sought to revert to by carrying out a purification, reform, and remedy of astronomy. That accounts for the great popularity of expressions such as *restitutio, restauratio, emendatio,* or *instauratio astronomiae* during that time (Burke 1980, p 139). All of these terms refer to a renewal, reform, and restoration of astronomy. By using them, astronomers intended to communicate that by proposing alterations to astronomical theories, they in fact aim at returning to astronomy's more original form hidden under the layers of Aristotelian and Ptolemaic deposits.

A typical representative of this tendency was Tycho Brahe (1546−1601), as witnessed by the titles of his main works: *Astronomiae instauratae mechanica* (1598) and *Astronomiae instauratae progymnasmata* (1602). In the former treatise, he writes he would wish astronomy to revert to its earlier pristine state and to be handed to posterity more repaired than ever before ([...] *scientia Astronomica in integrum restitueretur*) (Brahe [1598] 1923, p 9). Elsewhere, he expresses hope that astronomy shall be cleansed of errors and restored to its integrity (*Astronomia* [...] *ut mendis omnia purgata in integrum restituantur*) (Brahe [1598] 1923, p 87). Tycho strove for a reform of astronomy that would consist in a return to its idealised beginnings. To him, renewal of astronomy meant above all its purification from layers of errors and mistakes that covered this science in the course of time. Tycho thus did not see the changes to astronomy he proposed as progress into the future but rather as a reversion to an earlier, more perfect state.[3] What we see here is still a retrograde conception of the history of astronomy. Where it is novel, however, is that here the *instauratio astronomica* is supposed to be carried out by humans without God's help. Tycho does not refer to any divine illumination, to no divine gift. Purification and improvement of astronomy is fully the work of human intelligence, patience, and self–sufficient diligence that does not need to rely on any help from above.

[3] Another representative of this approach was Petrus Ramus (1515–1572), whose ideas concerning history of mathematical disciplines have been recently thoroughly examined by Robert Goulding (Goulding 2006, Goulding 2010; Jardine and Segonds 2001).

## 4 Theory of Interrupted Progress

In 1630s, chapters on the history of astronomy started being called *de progressu astronomiae* (see the works quoted below). At that time, most astronomers, including proponents of heliocentrism, still accepted the biblical framework of their science, and therefore tried to incorporate into its history the notion of antediluvian astronomy using a conception one may call a theory of interrupted progress (Petri 1990, pp 50–132). According to this view, astronomy did experience progress but this progress had two beginnings: The progress started for the first time in the antediluvian era when people thanks to their longevity developed excellent astronomy. This gradual, cumulative evolution was, however, interrupted by the great flood and this antediluvian knowledge was irretrievably lost (though the first people tried to hand it down to their descendants on stone pillars). After the flood, people had to start learning about the heaven again from the start. This time, though, they did not have the advantage of longevity which was denied by God to Noah's descendants. The progress of learning astronomy thus started again, for the second time, from primitive beginnings. Such a conception we can find by different authors of the 17th century. We can mention the Dutch scholar Martinus Hortensius (1605–1639) and his *Carmen de progressu astronomiae* (Hortensius 1632, pp ii–iii; cf. Hortensius 2006), or the French astronomer Ismaël Bullialdus (1605–1694) who wrote about the history of astronomy at the beginning of his defence of the Keplerian astronomy *Astronomia philolaica* (Bullialdus 1645, pp 8–13). Further evidence is to be found in the history of mathematical sciences presented by the Jesuit Claude Francois Millilet de Challes (1611–1678) (De Challes 1690, pp 75a–76b), in the *De quattor artibus* (Vossius 1650, pp 142–145) by the Dutch Classical scholar Gerardus Vossius (1577–1649), in the preface to biography of Tycho (Gassendi 1964, pp 368–370) by the French philosopher and astronomer Pierre Gassendi (1592–1655) and at the beginning of *Machina coelestis* (Hevelius 1673, pp 9–11) written by the Polish astronomer Johannes Hevelius (1601–1677).

What was important in this theory of interrupted progress was the fact that early modern astronomers and historians (see above) tried to explain the origins and history of their science using historical and anthropological arguments which were no longer theologically motivated but rather based on contemporary anthropological knowledge gained especially in contacts with non–European cultures. First of all, early modern astronomers tried to explain what – both before and after the great flood – inspired people's interest in the skies. To account for this, three theories were proposed in 17th century (Goulding 2010, pp 1–16). According to the first theory, it was natural curiosity that inspired the development of astronomy: people have always been drawn to the beauty of the night sky, they have always been interested in the phenomena that transpired there. They soon noticed that in the sky, everything happens according to some order and consequently, they wished to know that order. A second theory, found already in Aristotle's writings, was based on the notion that sciences were created from surplus, as a product of abundance and luxury. Only when the basic needs of humankind were provided for, people had enough leisure time to devote themselves to the sciences such as astronomy. Astronomy is thus one of the side–effects of achievements of civilisation. The third theory of astronomy's origins came from Herodotus, according to whom geometry was created in Egypt as a result of the need to measure the boundaries of various plots and estates. According to this approach, mathematical sciences, including astronomy, were always born from the need to solve some practical problem. In the case of astronomy, the problem to be addressed was mainly the measurement of time both during the day and during a year, as well as maritime navigation. By the eighteenth century historians of astronomy, it was this third theory that became most popular (see especially such eminent 18th century works on the history of astronomy such as Weidler 1741; Montucla 1758; Savérien 1766).

## 5 Conclusion

The belief in antediluvian astronomy persisted in explanations of the history of astronomy until relatively late, almost until the end of the eighteenth century. Its character, however, evolved. In the sixteenth century, the notion of antediluvian astronomy was based simply on faith in biblical history and belief in Classical authors. Gradually, this conception was naturalised, meaning it sought natural explanations for the existence of astronomical knowledge among the first people. Only towards the end of the eighteenth century did the idea of continuous, cumulative progress prevail.

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# The History of Science and Science Education: a *Planetarium* at School

**Enzo Bonacci**

**Abstract.** The Livio Gratton is a small size *Planetarium* (40–seat capacity) located in Latina (near Roma, Italy); it belongs to the Scientific High School G.B. Grassi since its construction in 2003. In less than eighteen months of activity the number of admissions has been superior to 4000, but the situation was rather different previously, when the almost absolute lack of information about the structure and the few visitors induced the headmaster to accomplish a managing, cultural, educational and scientific valorization policy. Such galvanizing experience is worthy to be described from the discouraging premises till the positive response from audience and critics.

Key words: Planetarium, Measurements at School, Valorization policy, Historical astronomical educational elements

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## 1 A short Introduction

The aspiration to have the night sky at our disposal has been progressively satisfied from the ancient Farnese atlas (Schaefer 2005) until the largest *Planetarium* in the world located in the Nagoya City Science Museum[1].

A modern response to the primeval dream to attain an accurate miniaturization of the celestial sphere is thus supplied by the *Planetarium*, a circular room where suggestive projections onto a domed ceiling make possible to study the many facets of Astronomy at will. The contemporary history of planetariums started with the projector Model I built by the Carl Zeiss company in Jena (Germany) and its first public show held at the Deutsches Museum in Munich on October 21, 1923.

The Italian oldest *Planetarium* was inaugurated on October 28, 1928, in the octagonal *Hall of Minerva* by the *Baths of Diocletian*, with the Zeiss Model II star projector donated by the German government. Today we may admire that original instrument inside the new *Planetarium* of Rome[2]. We may classify the planetariums as follows:

1. Optical–Mechanical, with the traditional star–ball projector.
2. Digital, with high–resolution images processed by a computer.
3. Hybrid, with the star–ball plus a digital video imaging system.

Named after the famous Italian astrophysicist Livio Gratton (1910–1991), the *Planetarium* of Latina was inaugurated on December 20, 2003. It belongs to first type (Optical–Mechanical) and it is equipped with the Gambato's BS3200–A optical system projecting 2400 stars; it has a 6m (19.5') diameter dome and a capacity of 40 spectators.

## 2 How a *Planetarium* can Work at School

Very briefly, the relevancy of a *Planetarium* at school is related not solely to the interest and emotion which it unfailingly arouses in students, but

[1] Via: www.ncsm.city.nagoya.jp/en/planetarium/index.html

[2] Via:www.planetarioroma.it/il_museo/planetario/il_progetto/progetto_scientifico/zeiss_ii [The previous web–url*s*, and the others hereinafter reported are retrieved at current data].

also to the possible discovery of Astronomy or Astrophysics as a profession. The origin of Science coincides with the systematic observation of the sky and any new cosmological model has represented a fundamental step in this path, it is therefore easy to understand the importance of such a structure within a secondary school.

As key educational tool, since the celestial sphere is the object of study of foundations of science, epistemology and philosophy, a *Planetarium* can become the mainstay of any educational project including a laboratory of Astronomy. In the *Planetarium* Livio Gratton one may observe:

1. The representation of planets of the Solar System.
2. The celestial sphere and the precession of the equinoxes.
3. The movements and the eclipses of the Sun and the Moon.
4. The representation of a supernova and of a type Sc spiral galaxy.
5. The supernova blast, in particular, is reproduced by mixing different size lights from a nebula–like luminescent background on the dome.

## 3 Notes on the Educational Streams

The last years' experience has confirmed that the *Planetarium* is an effective tool of learning Astronomy and Science available for the whole school community. Static and moving projections, appropriately explained by expert speakers, have allowed students from any grade school to get an actual understanding of the motions of the celestial bodies. Supplementary lessons, in collaboration with qualified scientific societies, have extended the Astronomy teaching beyond the celestial mechanics, e.g., to the astrophysical phenomena. The main educational activities have been the following:

1. The International Year of Astronomy in Latina (2010–04–24)[3].
2. The ESA–HSF project "Greenhouse in Space" (2011–02–17)[4].

[3] Via:www.provincia.latina.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6039

[4] Via:http://grassi.deltaeffe.it/index.php?option=com_content&view=article&id=292:greenhouse-in-space-2011&catid=49:latest-news&Itemid=104

3. Grassi's students reaching scientific excellence (2011–03–14)[5].
4. The International Year of Chemistry in Latina (2011–04–30)[6].

## 4 Notes on the Cultural Achievements

The cultural exigencies recently shown by Latina, one of the rootless cities founded in Italy last century, have characterized the *Planetarium* Livio Gratton as important cultural centre[7] especially for young people, but not only. The organization of conferences[8] and meetings[9] on astronomical (Bonacci 2011a, 2011b), astrophysical[10], physical (Bonacci 2011c, 2012) and other[11] topics has also involved segments of society never interested in scientific issues before[12]. The principal cultural activities have been the following:

1. A GIREP–EPEC poster on the *Planetarium* of Latina (2011–08–02)[13].
2. A GIREP–EPEC poster on the GHIS project (2011–08–02)[14].
3. An IPS talk on the *Planetarium* experience (2011–09–26)[15].

[5] Via:http://grassi.deltaeffe.it/index.php?option=com_content&view=article&id=295:rinascimento-scientifico-del-grassi&catid=49:latest-news&Itemid=104

[6] Via:http://grassi.deltaeffe.it/index.php?option=com_content&view=article&id=300:liyc2011-al-grassi&catid=49:latest-news&Itemid=104

[7] Via:http://grassi.deltaeffe.it/index.php?option=com_content&view=article&id=269:audizione-in-commissione-cultura-per-il-planetario&catid=49:latest-news&Itemid=104

[8] Via:http://grassi.deltaeffe.it/index.php?option=com_content&view=article&id=320:lesperienza-del-planetario-in-finlandia&catid=49:latest-news&Itemid=104

[9] Via:http://grassi.deltaeffe.it/index.php?option=com_content&view=article&id=352:incontro-caffe-ipazia&catid=49:latest-news&Itemid=104

[10] Via:http://grassi.deltaeffe.it/index.php?option=com_content&view=article&id=287:stage-di-astrofisica-2011&catid=49:latest-news&Itemid=104

[11] Via:http://grassi.deltaeffe.it/index.php?option=com_content&view=article&id=356:lamor-che-move-il-sole-e-laltre-stelle&catid=49:latest-news&Itemid=104

[12] Via:http://grassi.deltaeffe.it/index.php?option=com_content&view=article&id=315:lannus-mirabilis-del-planetarium&catid=49:latest-news&Itemid=104

[13] Via:https://congress.cc.jyu.fi/girep2011/schedule/proceedings/pdf/1012.pdf

[14] Via:https://congress.cc.jyu.fi/girep2011/schedule/proceedings/pdf/1033.pdf

4. An IPS talk on the ESA–HSF project GHIS (2012–09–10)[16].

## 5 Conclusion

The kind of experiences and presentations of the celestial phenomena obtained by employing the *Planetarium*'s devices[17], in a *spectacular–educational* way, involved equally both *education* and *culture*. Thus, the *Planetarium*'s special activities met a demand for a growing public attention[18] towards astronomy and its history, by giving the spectators a chance to interact with skilled researchers during entertaining performances. The most significance and spectacular events were:

1. The "Moon Watch Party 2010" in Latina (2010–09–18)[19].
2. The Hubble's double anniversary in Latina (2010–11–20)[20].
3. The flight of Yuri Gagarin's 50th anniversary (2011–03–05)[21].
4. The Space Shuttle's 30 years celebrated in Latina (2011–06–04)[22].
5. The "Bon voyage, Voyager–1!" astronomical event (2011–10–29)[23].
6. The "Year of the Solar System 2012" in Latina (2012–03–27)[24].

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[15] Via:http://grassi.deltaeffe.it/images/modulistica/archivio/fisica/esperienza_del_planetario_prof_enzo_bonacci.pdf

[16] Via:http://grassi.deltaeffe.it/images/modulistica/archivio/fisica/Atticon6905_VI_C_1_by_Enzo_Bonacci.pdf

[17] Via:http://grassi.deltaeffe.it/index.php?option=com_content&view=article&id=333:la-nuova-insegna-del-planetario&catid=49:latest-news&Itemid=104

[18] Via:http://grassi.deltaeffe.it/index.php?option=com_content&view=article&id=367:il-planetario-del-grassi-tra-i-big-ips&catid=49:latest-news&Itemid=104

[19] Via: www.q4q5.it/modules/news/article.php?storyid=4774

[20] Via:http://grassi.deltaeffe.it/index.php?option=com_content&view=article&id=265:double-hubble&catid=49:latest-news&Itemid=104

[21] Via:http://grassi.deltaeffe.it/index.php?option=com_content&view=article&id=288:gagarin-celebrato-al-grassi&catid=49:latest-news&Itemid=104

[22] Via:http://grassi.deltaeffe.it/index.php?option=com_content&view=article&id=310:30d-dello-space-shuttle-al-grassi&catid=49:latest-news&Itemid=104

[23] Via:http://grassi.deltaeffe.it/index.php?option=com_content&view=article&id=327:bon-voyage-voyager-1&catid=49:latest-news&Itemid=104

[24] Via:http://grassi.deltaeffe.it/index.php?option=com_content&view=article&id=360:anno-del-sistema-solare-2010-2012&catid=49:latest-news&Itemid=104

Finally the campaign started in 2010 with the launch of the song *Planetarium Experience* by *Tremble rock band* and then continued with the organization of full–immersion shows based on topical subjects.

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# Digitization and Online Publishing of the Whole Historical Archives of the Department of Astronomy of the University of Bologna

**Fabrizio Bònoli, Elena Cenacchi, Agnese Mandrino, Raffaella Stasi and Diego Zuccato**

**Abstract.** We present the first results of a project of digitization of the whole Historical Archives of the Department of Astronomy of the University of Bologna. The original documents are being digitized both at low and high resolution and stored as metadata. The watermarked low–resolution images are being published online, so that researchers can easily preview the original and largely unpublished archival materials.

Key words: History of Astronomy, History of Science, Archives, Database

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## 1 A Short Introduction: the Archives

The astronomical archives of the University of Bologna contain records from the end of 17th century to the half of 20th (Zuccoli 1994). They are related both to the scientific activity of astronomers (logbooks, letters, manuscripts, projects, drawings, etc.) and to the administrative life of the astronomical institution in Bologna. Founded in 1711 by Count Luigi Ferdinando Marsili as Specola of the Istituto delle Scienze in Bologna, it was the first public observatory in Italy and the third in Europe (Baiada, Bònoli and Braccesi 1995; Bònoli 2009). The documents are divided into four archival series: astronomical and meteorological observations (respectively 52 and 127 logbooks), miscellaneous papers (66 boxes), Guido Horn d'Arturo's private correspondence (the *Fondo Guido Horn*: 10 boxes). The boxes numbered 1–61 represent the most extensive series. They contain, among others, a precious collection of correspondence between astronomers working in Bologna and scientists from all over the world: e.g. Giovanni Domenico Cassini (1625–1712), Giacomo Filippo Maraldi (1665–1729) Paris Maria Salvago (1643–1724), Luigi Ferdinando Marsili (1658–1730) Geminiano Montanari (1633–1687), Francesco Bianchini (1662–1729), Johann Jacob Scheuchzer (1672–1733), Antoine–Francois Laval (1664–1728), Ottaviano Fabrizio Mossotti (1791–1863).

The archives had been organized by Guido Horn d'Arturo (1879–1967), director of the University Observatory in the first half of 20th century (Bònoli 2003, 2007), following both chronological and by–subject methods.

On 1999 a wide project for the organization of all the Italian astronomical archives was promoted by the Italian Astronomical Society (SAIt), the Ministry of National Heritage and Culture (MBAC) and the National Consortium for Astronomy and Astrophysics (CNAA) (Foderà and Mandrino 2000)[1]. Since 2002 the project has been supported by the National Institute of Astrophysics (INAF), heir of CNAA (Gargano, Gasperini and Mandrino 2010). The aim of the project, named *Specola*

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[1] The original project via: www.archivi.beniculturali.it/servizioII/progetti/specola/progspecola.html, and at: http://sait.interlandia.net/node/44, in the Web site of the Italian Astronomical Society: www.sait.it. [The previous web–url*s*, and the others hereinafter reported are retrieved at current data].

*2000*, was to survey all the archival materials in the Italian historical astronomical institutions to order them (if needed), to produce inventories of the archives and to make them available on the Web (Pastura 2005; Chinnici, Mandrino and Bònoli 2006). Formerly, in the Nineties, the Bologna astronomical archives were started to be reorganized (leaving the original Horn's order), inventoried and published online (Peperoni and Zuccoli 1998). The work had been completed within the *Specola 2000* project and under the supervision of the local Superintended to Archives, and the inventories could have been accessed in sequence and searched by string. As a natural improvement of *Specola 2000* and thanks to financial support of Sistema Museale d'Ateneo of the University of Bologna, we developed the project of digitization of the whole archives – more than 70.000 *folia* – and to publish them online. The archives deal not only with astronomy, but even with physics, mathematics, meteorology, technology, history of institutions, social sciences, single persons, etc., and they are visited by a wide number of researchers. Aim of this project is to widen as much as possible the knowledge of our archives, making them available online, so that scholars can easily preview the original and largely unpublished archival materials, preserving their condition as well.

## 2 The New Digital Archives

The scope of the new digital archives is to supply a fully searchable web interface that allows complex searches on the archives inventory, aimed at finding the description of the single element and at inspecting the high–quality low–resolution images of it. Since a digital version of the archives inventory was already published on the library web site, we kept as a requirement a layout similar to the existing one.

### 2.1 Digitization Technique and Output File

Each element will be scanned with an overhead scanner, equipped with bookcradle and protective glass, optimized for ancient books and manuscripts (low exposure to light, no UV radiation) and three folders are created for each element:

- High resolution 600 dpi .tif images (digital master, for conservation and reproduction purposes; expected total size: ~ 7.5 TB).
- Low resolution compressed .jpg images (on–site browsing).
- Low resolution compressed and watermarked .jpg images (on–line browsing; expected total size: ~ 7.5 GB ).

## 2.2 Data Storage and Dissemination: Database and Metadata

The descriptions of the elements, currently stored as pieces of text in plain HTML files, will be marked–up and stored in a MySQL database whose structure will follow the general international archival standard description, ISAD (cfr. ISAD(G) 2000). The database will satisfy the following purposes:

- Enables the dynamic exposure of the data, and particularly the advanced search through the inventory (search by period, author, etc.), by means of coupling with PHP files.
- Enables the production of XML files which describe the archives and their digital representation (images and description), following different standard models; e.g. EAD edited by the International Council on Archives (cfr. Encoded Archival Description 2002), and EDM edited by Europeana (cfr. Definition of the Europeana Data Model elements 2012).

Once the XML files are produced, according to the preferred standard, the digital archives can be exposed on international libraries, such as ICARUS APEx and EU Europeana. Converting from plain text to a database leads to the need of disambiguation and, often, requires an archivist intervention to better specify what–is–what. It requires multiple interactions to obtain a structure flexible enough to accept uncertain data and rigid enough to avoid ambiguities. The hosting itself of the data is not critical: a standard virtual host with enough disk quota (for both the low–res images and their thumbnails) and a small MySQL database is sufficient. Server load is acceptable even when generating thumbnails. Our code, anyway, allows for scripts being terminated by timeout condition while generating thumbnails for big directories without problems. Displaying watermarked low–res images leverages the functionality of Lightbox script, a technique used to overlay images.

## 3 Conclusion

The project is still being worked on, and even major modifications can still happen. The most important (and difficult) parts are the selection of metadata fields to use, and the correct assignment of metadata to the source material: the presentation can then change without major rework. At the moment have been digitized more than 30.000 images.

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# The Ontological Levels of Scientific Theories and Technical, Ethical and Educational Progress

**Giuseppe Boscarino**

**Abstract.** What I discuss in my paper is the following: Does science deal only with *facts*? Does ethics deal only with *values*? It is shown as, in the science progressive working, *what is*, *what has to be*, *what can be,* and *what ought to be* are interconnected. The *rationalistic and humanistic tradition about the way to make science* and *to teach it* can establish a modern progressive education.

Key words: Ontology, Scientific theories, Traditions of thought, Ethical–Educational aspects of theories

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## 1 Positivistic and other Solutions of the Questions

For a lot of the publications of the twentieth century it was considered in relation to above–mentioned questions: a) that science deals with and should deal only with *facts*, or with *what is*; b) that the ethical choices or values, *what ought to be*, concern personal beliefs, which have nothing to do with science, *because from this one values cannot be deducted.* Let us read what they write about it, in many places, and how they argument, referring to the so–called *naturalistic fallacy* by Hume (Hume 1739). The famous passage of Hume is the following:

> In every system of morality, which I have hitherto met with, I have always remarked, that the author proceeds for some time in the ordinary way of reasoning [...] when of a sudden I am surprised to find, that instead of the usual copulations of propositions, *is*, and *is not*, I meet with no proposition that is not connected with an *ought*, or an *ought not*. This change is imperceptible; but is, however, of the last consequence.[1]

Here what the positivistic Ayer writes about it:

> There cannot be such a thing as ethical science, if by ethical science one means the elaboration of a «true» system of moral.[2]

The fact that there can be no science of ethics, according to Karl Raimund Popper (1902–1994) post–positivistic, is the foundation of an open, tolerant and democratic, society, because the constraints of science fail – *Ethics is not science* – he wrote (Popper 1966); ethics has no truth, it is without truth, being everyone free to give himself his values and his moral choices.

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[1] Hume 1739 [Book on *Morals, Part I. of Virtue and Vice in General, Sect. I. Moral Distinctions Not Derived from Reason*] pp 230(–232).

[2] Ayer 1936, p 116. Author's quotations marks.

## 2 To have to be of Science and to be of Knowledge

Now let's ask to ourselves: Is it really true that science deals with declarative or descriptive propositions, leaving the field of prescriptions to ethics? In the body of scientific theories, which are theorems, about what one declares *what is* or *what can be*, the thesis, it is said then as meta–declaration that this *had to be proved*. Thesis' *to be or can be* then is *knowledge's to be*, *the prove's to have to be* is *science's to have to be.* Kepler states his law that planets move on elliptical orbits around the sun, on one of its fires (knowledge's *to be),* but nothing excludes that they can move on some other geometric orbit. Isaac Newton (1642–1727) argued (Newton 1687) thanks to its theory, that if certain hypothesis and conditions are true, planets cannot move but on elliptical orbits. This is the *to have to be* of science. Newton turns a description into a prescription. The progressive circle of knowledge is then going from descriptions to prescriptions and from prescriptions to descriptions, to the discovery of *new things*. If certain hypothesis and conditions or laws are true, then certain knowledge or descriptions are true. Hence the famous case of the discovery of the planet Neptune, thanks to Newton's theory, in the field of astronomy. Hence the power of cognitive discovery of theory or the *deductive method*, as highlighted in an excellent way by Giovanni Vailati (1863–1909), a disciple of Giuseppe Peano (1858–1932):

> It's fair to say that it was in some ways the more extensive and systematic application of the deduction to the study of the phenomena of nature, which provided the first impetus to the development of modern experimental methods.[3]

*Then which makes to progress is science, while which advances is knowledge. Science is essentially a method* that turns descriptive propositions into prescriptive propositions, *what is* or *what can be* into *what has to be*, *the fact* into *cognitive value*, into what is judged *worthy* of knowledge and then appreciated. The *advancement of knowledge* is to turn prescriptive propositions into descriptive propositions, the *progress of science* is to turn descriptive propositions into prescriptive propositions.

[3] Vailati 1911, p 125.

Today man wants to dominate his future increasingly; this forced him to study, with the methods of science*, trends and potentialities* in natural and social processes, and, among these ones, what is worthy of being pursued in ethical and social practice, *what ought to be – value,* and *what should be taught in education work.* In truth what they want to deny is that *science, as theory can make rules for the actions of men, in view of their corporeal, material and intellectual will–being, you want individual or collective.* First of all it is then to sound in science's working, in its founding categories.

## 3 Different Conceptions of Philosophy and Science in the History of Scientific Thought

Between scientists and philosophers of science the field has so been disputed among the ones who have conceived science as a science of *what is*, which may be phenomena and/or essences, *what has to be*, which lies behind the phenomena, the ones who conceived science as a science of *what can be*, that are potentialities or trends whose reality is considered made, and the ones who conceived science as a science of *what ought to be*, what among the potentialities is worthy to be known and implemented by human working. For Aristotle (BC 384–322) science has as its foundation the category of necessity, *what has to be* [*to ti en einai*] in Greek text (Aristotle VII, 6, 1031, 65e), for Georg Wilhelm Friedrich Hegel (1770–1831) the task of philosophy, which for him is the real science, is "to understand what is, because what is is reason" (Hegel 1821), for Marx the task of science is not to interpret the world, but to transform it, to say *what ought to be*, because *what can be*, the *not–yet*, to paraphrase the philosopher Ernst Bloch (1885–1977) it is the *true–being*. Recently the category of the possibility was discovered not only by philosophers but also scientists as foundational category of science, indeed some put it as the basis of Quantum Mechanics (QM). One of the fathers of QM, Werner Karl Heisenberg (1901–1976) wrote that quantum theory mathematical laws can be interpreted as a quantitative formulation of Aristotle's concept of *dynamis* or *potential*. In effect, the category of possibility or potentiality is intrinsic to QM theoretical structure itself. The wave function expresses in QM the overlap of the different potentialities of the observable. Imitating the style of the Ionic philosophers, the latest Popper (Popper 1982) writes that *All is propensity*. Expressed in Aristotle's terminology, this can, in his opinion, mean that the being is the actualization of a propensity to become Ilya Prigogine (1917–2003), one of the main authors of so–called new science of chaos, who argued that the *laws of chaos*, do not describe any more a close world, subjected to a deterministic intelligibility, but an open world, where the category of probability, that is of *possibility*, is fundamental.

## 4 Scientific Theories and Ethical–Educational Progress

We now elucidate the different ontological levels within which the work of science moves. The ontological status of *phenomenalistic* or *essentialist* type leads to conceive the scientific theory, in the taxonomic sense. The ontological status of potential type leads to conceive the scientific theory in *provisional* sense, as science not only of *what is* or *what has to be,* but also of *what can be* or can happen over time. The ontological status of axiological type, i.e. of what among potentialities must be known and is worthy of being implemented, leads to stress, however, the *ethical–educational aspect of the theory*; this has to choose, among potentialities which of these is worthy of knowing and pursuing in ethical, political and educational acting. *Ontology, axiology, and epistemology are thus not separable in any philosophy or metaphysics of science, as in working of the same scientist.* Meanwhile, the potentiality cannot be an *ontological category of reality*, which is indeed *that it is* (at this level, in our opinion, in its metaphysical meaning, Parmenides' dictum is valid: *being is, not being is not; this one, in fact, neither can be thought nor can be said*), but an *epistemological category*, i.e. of scientific theory, in which the phenomenon, the apparent being is divided between what it is rebuilt, the *scientific fact*, what underlies it, the essence, i.e. *the elements of the theory and its laws*, (this is the level of *what is*, *the level of logic of scientific discovery*), as in it (the phenomenon) *can be*, the possible (this is the level of *what can be*, of *logic of invention and of scientific and technical progress*) and as in it among the possibilities *ought to be* (this is *the ethical–political–educational level*), *the value*, or what is worthy of being known and pursued by human acting, either by man as a single or by man as a member of a society. It is said that technocracy is the supremacy of technology over ethics; if you can, ought; "can implies ought" has been written. Here the passage is from *what can be* to *what ought to be*. What mediates *what can be* to *what ought to be*? *Who leads the scientist to value* *and to choose, to what ought to be if is not reason?* May it be feeling, blind intuition, conformism, tradition, his religious convictions, his prejudices of some kind, the authority and power of those who direct his work as a scientist and a technician, that is as much of irrational is in him? Every theory is born mixed with expectations, hopes, projects, thoughts, needs, career interests, gain, prestige, domination and power, etc. Karl Marx (1818–1883) rightly wrote (1867) about the difficulties (*The Furies of private interest)* of the political economy develop itself as a science.

## 5 Science's Rationalism and Ethical–Educational Progress

The fact is that in the history two great traditions of thought are clashed on the concept of scientific theory and reality, with what this has meant in terms of ethics and education, or, the *empirical tradition* (Aristotle) and the *rationalistic one* – Pythagoras (BC 570–495) Parmenides (fl. BC V century) Democritus (BC 460–370) continued by Galileo Galilei (1564–1642) and Newton – (Boscarino 1999). The former has conceived reality as given by the senses, for which science is mere taxonomy. Rational scientist, driven by *the logic of the invention,* thanks to idealization processes that he brings into being, constructs or imagines, from the empirical reality, abstracting and combining properties, *models of reality*, which he submit to verification or falsification, and that he enriches more and more with new properties, either to better understand the empirical reality complex in itself, or to submit it to *chance's tests*. It is clear that the empiricist, for whom reality is precisely the empirical, as it occurs, is led to identify values with facts (*value = fact*), ethics, as *knowledge of what ought to be*, with custom, descriptive rules with prescriptive rules. On the ethical, political and educational plane, all this induces to conformity, to the flattening of ethic and educational values to the socially accepted and dominant facts, to the loss of own identity and individuality, which should be producing values and ideal tensions, but in fact is devoid of great ethical virtues of creative man, such as *faith*, *hope* and *strength of mind* and *the courage of the change*. Enlightenment humanism's dictum is according to Immanuel Kant (1724–1804) *have courage to know* (Kant 1784). For Fromm *empiricism* and *rationalism* are two existential modalities, the former of *having,* the later of *being*. We are free and responsible only if we know, produce science and bring being values. Only *the conception of a scientific theory that is not reified, but humanistic*, can lead to *ought to be* of a sympathetic society.

## 6 Conclusion

Putnam's pragmatistic solution (Putnam 2002) of the presumptive dichotomy *facts–values* therefore appears confuse on the philosophical and epistemological plane and unconvincing on the plane of a progressive educational program, not knowing how to separate between science and knowledge in the scientific dynamic with its ontological layers, between common knowledge and scientific knowledge, between what the first has of layered in terms of conformism, of ambiguity and ideology, and the second in terms of potentialities, so enhancing the critical ability and the individual and collective creativities, between the plane of ethics and of custom. It is then the choice of the rationalistic and humanistic tradition of science, in our opinion, with what we have said, that leads to combine science and ethics, scientific and technological progress with ethical and educational progress, the facts and the potentialities of science with the values of ethics and education, the deductions of science with the prescriptions of ethics of *you ought to be*. If you *know and can*, according to what you build with science working, you *ought to* improve man according to what *ethical humanistic and scientific rationalistic tradition teaches you*.

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# The Polytechnic Schools in Germany in 19th Century

**Danilo Capecchi and Giuseppe Ruta**

**Abstract.** We present a short history of polytechnic schools, with main reference to Germany. We devote particular attention on the *Karlsruher Polytechnikum*, organized university-like. On the basis of some original archive documents, we draw some conclusions on the German higher technical schools.

Key words: History of universities, Polytechnics, History of engineering

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## 1 A Short Introduction

Studies on universities history are, among others, in the journal by the Oxford University Press[1]; the monographs by the Cambridge U.P. (Rüegg 1992); the *Annali di storia delle università italiane*, CLUEB, Bologna. Roughly speaking, the German university model appeared in Prussia, designed by Wilhelm von Humboldt (1767–1835), who followed Friedrich Schleiermacher's (1768–1834) liberal ideas, and was influenced by the pedagogic Johann Heinrich Pestalozzi (1746–1827). His goal was to demonstrate the process of the discovery of knowledge and to teach students to *take account of the fundamental laws of science in all their thinking*. In this contribution we focus on the organization of German polytechnics, taking as a model the *Polytechnische Schule zu Karlsruhe*, organized university–like. We will provide, on the basis of the original volumes containing the *Programm für das Studienjahr*, some sketch of the organization of the courses, some information on attendance and the like. Technical schools called *Bergakademien* were founded in Freiberg (1765) and Berlin (1770): in them, geometry, hydraulics, mining techniques, and chemistry were taught. In 1799 the *Bauakademie*, a school of architecture, was established in Berlin as part of the reorganization of the educational system, culminated in the opening of Berlin University in 1810. The *Technische Universität Berlin* was founded only in 1879, merging the previous *Bergakademie*, *Bauakademie*, *Technische Schule* (1821) and *Technische Hochschule Charlottenburg* (1879). The level of the *Bauakademie* was ranked below that of the university, since it was essentially professional (Manegold 1989, Christophe 2004, Capecchi and Ruta 2011). *Gewerbeschulen* were opened in the 1820–1830s, to ensure professional training and foster economic development. In 1821 a *Gewerbeinstitut* was opened in Berlin, totally devoted to industry. In other German states the *Gewerbeschulen* were less specialized, and the majority of the students in the first half of the century got positions in the public services. In the 1860s the *Gewerbeschulen* were turned into *Polytechnische Schulen*. In the late 1870s they became *Technische Hochschulen*, their control was moved from the ministry of commerce to that of education, and they were granted the same autonomy as universities. Workshop training lost its original prominence; efforts were

[1] http://ukcatalogue.oup.com/category/academic/series/history/hou.do#.UQ_IBBxnKGc

made to appoint teachers with good scientific credentials. From the 1850s to the 1880s we see a remarkable growth of students of technical schools. Germany was pioneer in teaching laboratories, adopted extensively by the *Technische Hochschulen* in the 1880s. The availability of laboratories of mechanical and electrical engineering, material testing, applied chemistry was the mark of modern, high quality schools, among which those in Berlin were particularly important. The cause of technical schools was well supported by the German society of engineers, *Verein Deutscher Ingenieure*. At the turn of 20th century the *Technische Hochschulen* were granted the right to award doctoral degrees in engineering.

## 2 The Polytechnic School in Karlsruhe

The grand duke Ludwig von Baden (1763–1830) founded the technical school in Karlsruhe in 1825, inspired by the Parisian *École polytechnique*. Thus, we read *Großherzogliche Badische Schule* in the original school programs. In 1832 of a *Forstschule*, devoted to forest sciences, was also founded. The grand duke Friedrich I (1826–1907), son of Ludwig, merged the schools into a *Technische Hochschule* and then, in 1885, into a *Polytechnische Hochschule*. The grand duke went on patronizing the school, with donations and regular visits on feast occasions, as reported in the programs of the school. The patronizing reached the point that the polytechnic was called *Fridericiana* starting from 1902, as stated in the front page of the school programs from that year on. In addition, the school was one of the first in Germany (1899) to release doctorates in applied science (*Doktor–Ingenieur*), similar to those released by the universities. The first woman in Germany to get this degree was in Karlsruhe in 1903.

In the last decades of 19th century and first of 20th, many famous people in pure and applied science were students or staff in Karlsruhe. We may quote the mathematicians Georg Hamel (1877–1954) and Ernst Schröder (1841–1902), the physic Heinrich Hertz (1857–1894), with fundamental experiments on electro–magnetism in Karlsruhe, whence the *Hertz–Hörsaal* in the polytechnic, the chemist Fritz Haber (1868–1934), who later won a Nobel prize, the civil engineer Friedrich Engesser (1848–1931), known for bridge construction and structural mechanics, the mechanical engineers Carl Benz (1844–1929), Franz Grashof (1826–1893), Emil Skoda (1839–1900), August Thyssen (1842–1926), to mention but a few. With the aim of getting an insight of the actual school organization, we examined the original programs of the above quoted period, and we will report some news in the following tables 1 and 2.[2] In particular, we will show a sketch of the syllabus in civil and mechanical engineering, and we will give a hint on the students and the basic facts of the organization of the polytechnic at the turning of the century. The academic year we will report is 1900–1901.

**Table 1** Civil engineering (*Ingenieurwesen*)

| First semester | Second semester | Third semester | Fourth semester |
|---|---|---|---|
| Analytical geometry in the plane | Differential & integral calculus II | Differential equations | Technical mechanics |
| Differential & integral calculus I | Analytical geometry in space | Theoretical mechanics I | Theoretical mechanics II |
| Descriptive geometry I | Descriptive geometry II | Problems of theoretical mechanics | Problems of theoretical mechanics |
| Landscape architectural drawing | Experimental physics II | Technical mechanics | Hydraulics |
| Experimental physics I | Organic experimental chemistry | Graphical statics | Strength of materials |
| Inorganic experimental chemistry | Technical architecture I | Mineralogy | Perspective |
| Technical architecture I | Landscape architectural drawing | Earth morphology | Geology |
| Design of building elements | Design of building elements | Design of building elements | Ground works |
| Theory of machines | Theory of machines | High steel buildings | Design of building elements |
| | Free–hand drawing | General economy | High steel buildings |
| | | Social laws | Economy and commerce |
| | | | Transportation |
| | | | Labour laws |
| Fifth semester | Sixth semester | Seventh semester | Eighth semester |
| Practical geometry | Bridges II and design | Higher geodesy | Practice in geodesy III |
| Practice in geodesy I | Steel structures | Method of least squares | Construction of streets and railways |
| Iron buildings and | Theoretical steel and | Tunnelling and | Design of bridges and |

[2] We are indebted with Dr. Klaus Nippert for the original archive documents.

| | | | |
|---|---|---|---|
| bridges I | bridges | mining | railways II |
| Construction in stone | Bridges III | Construction of streets and railways | Design of channels |
| Tunnelling and mining | Ground works | Railway management | Dams and water channels |
| Machine elements I and design | Dams and water channels | River and lake buildings | Water supply |
| Financial sciences | Foundations | Design of channels | Water management |
| Social legislation | Design of machines | Design of bridges and railways I | German constitution and administrative law |
| | Practice in geodesy II | Technological culture | |
| | Economy and commerce | Applied economy | |
| | Transportation | Principles of civil right | |
| | Labour laws | | |

**Table 2** Mechanical engineering (*Maschinenwesen*)

| First semester | Second semester | Third semester | Fourth semester |
|---|---|---|---|
| Analytical geometry in the plane | Differential & integral calculus II | Differential equations | Synthetic geometry II |
| Differential & integral calculus I | Analytical geometry in space | Synthetic geometry I | Theoretical mechanics II |
| Plane and spherical trigonometry | Descriptive geometry II | Theoretical mechanics I | Problems of theor. mechanics |
| Descriptive geometry I | Experimental physics II | Problems of theor. mechanics | Applications of perspective |
| Experimental physics I | Organic experimental chemistry | Graphical statics | Strength of materials |
| Inorganic experimental chemistry | Theory of machines | Elements of machines I and realization | Hydraulics |
| Theory of machines | Drawing of machinery | Fabrication of machines | Elements of machines II and realization |
| Technical architecture I and design of building elements | Design of building elements | Accounting for industrial plants | Lifting equipment |
| Free–hand drawing | Free–hand drawing | Social laws | Fabrication of machines |
| | | General economy | Physics laboratory |
| | | | Economy and commerce |
| | | | Transportation. |
| | | | Labour laws |
| Fifth semester | Sixth semester | Seventh semester | Eighth semester |

| | | | |
|---|---|---|---|
| Theory of machines | Building of steam machines | Mechanical laboratory | Construction of machines (steam turbines…) |
| Building of water motors | Construction of machines (water wheels, turbines…) | Construction of machines (steam turbines…) | Mechanical laboratory |
| Construction of machines (cranes, pumps, presses…) | Locomotives | Steel structures | Direct current technology |
| Mechanical technology | Mechanical laboratory | Railway management | Dams and water channels |
| Direct current technology | Mechanical technology | Tunnelling and mining | Foundations |
| Electric measures | Railways | Direct current technology | Water supply |
| Tunnelling and mining | Water supply | Kinetic theory of gases | Technical analysis |
| Technical chemistry | Direct current technology | Electrical railways | Physics laboratory |
| Industrial heating | Chemical technology | Telegraphy and telephony | German constitution and administrative law |
| Selected technical analysis | Selected technical analysis | Technical chemistry II | |
| Heating and ventilation | Elements of practical geometry and measurements | Selected technical analysis | |
| Physics laboratory | Transportation | Principles of civil right | |

We later sketch the other courses offered in the polytechnic, which offered two–year general course on mathematics and natural sciences (*Allgemeine Abteilung für Mathematik und allgemein bildende Fächer*) for those who either wanted to become middle school (or private) teachers, or who had not yet decided which technical course to attend. Students in Italy attended also a basic course before a three–years engineering special school. The programme of the general course at Karlsruhe, however, stresses that a complete basic education required lectures on civil and state right, history, literature, art history, and pedagogy. The school of architecture (*Architektur*) was actually a mixture of study of fine arts, of basics in mathematics and natural sciences, of elements of building techniques, of design and architecture pattern schemes. One also finds lectures in clay and plaster modelling in the syllabus, as well as guided tours to the state museum of art and painting gallery. There was no stress on structural mechanics: that was left, apparently, to the civil engineer. In the latter course, there was, on the other hand, a special sub–course devoted to a professional figure called *Geometer*, a kind of low–level technician in civil infrastructures with respect to the *Doktor–Ingenieur*. Electrical and chemical engineering (*Elektrotechnik* and *Chemie*) completed the education in industrial engineering, a sign of an up–to–date training and of the attention to the quick development of industry in both fields. Electrical engineering had teachings of: theory and measurements of direct and alternate currents; electric machines, plus laboratories on their construction; electro–magnetic theory of light; fabrication and applications of lighting rods, galvanic plasticity, telegraphy, telephony; electric lines and electric railways; electric oscillations. It is apparent how modern such teachings were in 1900. In addition, there was an optional *curriculum* providing a specialization in illumination technology, with indications to special chemical laboratories for those interested in gas illumination. Chemical engineering had three *curricula*: a general one for the science and the technology of chemical processes; one for food control; and one for chemical technologies and pharmacy. The latter two prepared for a final state examination. The three *curricula* had, as a common basis, the first three semesters, lecturing on: theoretical and applied chemistry, both inorganic and organic; pharmaceutical chemistry; botanic; zoology; several laboratory activities in microscopy and different levels of applied chemistry; pharmaceutics of plants; petroleum derivates; textile fibres technology; kinetic theory of gases; thermo–chemistry. Two semesters of autonomous research in a chemical or technical–chemical institution, under the direction of a tutor, completed the general *curriculum*. The *curriculum* devoted to food industry and control declares that the first six semesters should stress the preparation on hygiene, bacteriology, botanic, and court chemistry. The seventh semester was devoted to practical activities in a laboratory of the polytechnic, and two more semesters should have been spent in the state department for food control. The *curriculum* devoted to pharmaceutics was completed by two semesters of compulsory and optional teachings on technical chemistry, bacteriology, laboratory activity, microscopy, and practical work in the botanic institute of the polytechnic. This also is a clear sign of an up–to–date education, aimed at promoting quick interaction with the rapid emerging and developing industries in Germany, and the need for an efficient state organization in all aspects of life. The course in forest sciences is peculiar: lectures included some natural sciences (chemistry, mathematics, physics, botanic, zoology, mineralogy), plus fishing, fishing farms, forest entomology, plant knowledge, biology of cryptogams, meteorology, plant illnesses, anatomy and physiology of trees, mushroom parasites, wood rebuilding and maintenance, wood lanes and water flows, woods protection, plus the laws related to forest, fishing and hunting. It is apparent how, already at the turn of $20^{th}$ century (but it had been a part of the technical school since the first half of the $19^{th}$), this course has the aim of protecting woods and the environment as fundamentally interacting with all aspects of human life: wild animals, wood technologies, plantations, land protection, tourist activities. Thus, ecologic sensitivity of Germans seems to be rooted in the past. The programme for the academic year 1900–1901 emphasizes the description of the grand duke permission to release doctorates, elevating the polytechnic to the same rank of the universities. The senate of the school saw this as recognition of the school activity to promote progress and development of the country, hence the doctorate *ad honorem* to the grand duke and the dedication of the school. The programme concludes with some facts about the preceding academic year. Some 1300 people between regular students, guests and free audience followed the courses:

**Table 3** Population

| | General | Architecture | Civil | Mechanical | Electrical | Chemical | Forest | Total |
|---|---|---|---|---|---|---|---|---|
| Winter | 16 | 235 | 204 | 358 | 277 | 164 | 12 | 1364 |
| Summer | 10 | 213 | 201 | 376 | 272 | 154 | 10 | 1262 |

## 4 Conclusion

A general, yet very meaningful, comment is that Karlsruhe polytechnic is a formidable join of theory and practice. It is apparent, indeed, how lectures and laboratories, theory and workshops in class and *in situ* were seen as complementary and necessary to each other. We may extend this peculiarity to German polytechnics, and stress that this was an exception in Europe. Indeed, as a rule of thumb, French technical schools saw theory prevail over practice, while on the other hand English schools went the other way, favouring technical apprenticeship over a strong theoretical basis. This is for sure one of the causes of the enormous German industrial development after unification.

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# Attributions and Misattributions at the Origins of Special Relativity

**Marco Mamone Capria and MariaGrazia Manini**

**Abstract.** Minkowski wrote that a basic mathematical result (the Lorentz invariance of Maxwell equations) for the newborn special theory of relativity was "the theorem of relativity by Lorentz". We explain that this name is unwarranted, and that in fact among the founders of the theory it was Poincaré who came closest to proving it. It is argued that historians should be careful not to rely uncritically on the bits of historical reconstruction that for different purposes scientists insert in their technical papers.

Key words: Special relativity, Lorentz transformations, Electromagnetism, Fields vs. Potentials, Lorentz, Poincaré, Einstein, Minkowski

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## 1 A Short Introduction

The history of science is only in part the business of historians, since it has also very much to do with the search for recognition, which is an obviously important concern for scientists. For this reason in their technical papers scientists: 1) select carefully their references (not always coinciding with their true sources); 2) refer to previous contributions with varying emphasis and acknowledgements; 3) insert explicit bits of historical reconstruction (usually in their introductory sections) about the topic to which they intend to contribute. Then it comes the time when, for a sufficiently *mature* research topic, scientists also edit a collection of *main articles* (a *reader*), which will become a standard reference for newcomers to the topic and for historians alike, and will favour the oblivion of all the other contributions.[1] As a rule, historians build their own version of the facts helping themselves with the historical snippets provided in the technical papers and with the standard collections of papers. Also, when the secondary literature has grown to a sufficiently large amount, it tends to surrogate in the work of professional historians the direct consultation of the sources. The risk, as far as historical accuracy is concerned, is that an account which is to a considerable extent influenced, on one hand, by the drive to self–promotion and by school loyalty and, on the other hand, by uncritical reliance on the secondary literature may come to be elevated to historical truth and be perpetuated in science and history textbooks.

The main purpose of this paper is to provide an outline of our account[2] of a case of a remarkable, if neglected, case of *authoritative misattribution* concerning the rise of special relativity.

[1] In the case of the theory of relativity this role was fulfilled by the volume Einstein, Lorentz, Weyl and Minkowski (Einstein, Lorentz, Weyl and Minkowski 1923). The editors of this collection abstained from including any contribution by Poincaré.

[2] For a full account: Mamone Capria and Manini 2013.

## 2 Unifying the Electric and the Magnetic Fields

The understanding of the relationship between the electric and the magnetic forces is a major research effort in Nineteenth Century physics, with fundamental contributions, either theoretical or experimental, from physicists such as Hans Christian Ørsted (1777–1851), Michael Faraday (1791–1867), André-Marie Ampère (1775–1836), James Clerk Maxwell (1831–1879) and others. The culmination of this process can be seen in the formulation by Heaviside and Hertz of the so–called Maxwell equations, a building block and a model for subsequent theoretical physics. One of the basic mathematical targets of the founders of special relativity – namely, Lorentz, Poincaré, Einstein, Minkowski (Lorentz 1904; Poincaré 1905, 1906; Einstein 1905; Minkowski 1908, 1909, 1915) was to show that those equations were, exactly or approximately, invariant under what Poincaré called in 1906 the *Lorentz Transformations* (LT). This task involves, as a necessary ingredient, a derivation of the transformation laws of the electric and magnetic fields under LT.

Hermann Minkowski (1864–1911) gave this result the name of "[...] the theorem of relativity by Lorentz", emphasizing that it was a "[...] purely mathematical fact".[3] It is important to keep in mind that Minkowski, an eminent mathematician, was highly qualified for making such a claim and that surely he was not the kind of scholar who could make it lightly. *But was Minkowski's claim correct? And in case it was not, who was the author who came closest to proving that theorem?*

An analysis of the main contributions to what is known today as special relativity in the years 1904–1909 leads to a rather surprising result, which can be summarized as follows.

Lorentz did not prove the theorem Minkowski attributed to him, and, what is more, he was very far from even *trying* to prove it. Indeed, he was honest enough to admit as much in print some years later (1915), when special relativity was quite well received within an authoritative section of the physical community and was soon to be at the same time superseded and consecrated by the forthcoming general relativity (1915–1916).

[3] "Für jene ursprünglichen Gleichungen ist die Kovarianz bei den Lorentz–Transformationen eine rein mathematische Tatsache, die ich das *Theorem der Relativität* nennen will [...]" (Minkowski 1908, p 59, p 54).

As to Einstein, there is no doubt that in his electrodynamical paper of 1905 he *endeavoured* to prove that theorem, but his proof can be shown to have fatal flaws (it gives a sufficient, but not a necessary condition for the transformation of the fields), a fact that has passed more or less unnoticed by most commentators.

It turns out that the first scientist who gave what amounts to a sketch of a correct proof was Poincaré (1854–1912).[4] Our reconstruction of his proof is partly conjectural (Mamone Capria and Manini 2013, § 4.2.1–4.2.2), which is not surprising given Poincaré's expository style (Mamone Capria and Manini 2013, p 21, fn. 16), but it rests on good textual grounds.

The technical part of our reconstruction turns around the way electric and magnetic fields are determined in Maxwell theory by charge and current distributions, and the expression of the fields in terms of retarded potentials obeying inhomogeneous wave equations. Poincaré was well aware of this formulation of Maxwell theory (which actually amounts to a more restrictive version of it), while in his article Einstein worked solely with fields, which made his proof of the uniqueness of the transformation law of fields seriously defective.

Minkowski knew well Poincaré's work, in both pure and applied mathematics, and did cite his main relativity paper (Poincaré 1906 is cited in Minkowski 1908, p 54). So it is appropriate to ask why Minkowski should have missed an opportunity for giving Poincaré his due on this specific point (not to speak of other aspects of the newborn theory), and preferred instead to credit Lorentz with a mathematical discovery the latter had subsequently to deny having ever made. This is a kind of question which is in general rather difficult to answer, and that in our case is made especially difficult by the circumstance that both Minkowski and Poincaré died prematurely, in particular well before relativity had been widely recognized as a historical landmark by both specialists and cultivated people. However, a plausible answer can be devised by framing this episode in terms of the sociology of the national scientific communities of that time, and of the psychology of the individual scientists involved (Mamone Capria and Manini 2013, § 6).

[4] Let us note that his 1905 outline of the lengthy paper published in 1906 was registered at the French Academy of Sciences some three weeks before *Annalen der Physik* received Einstein's manuscript.

## 3 Commentary

Special relativity was the outcome of a complex development in the history of physics and of the philosophy of science, and the derivation of the transformation laws of the electric and the magnetic fields is just an ingredient (although a very important one) of the resulting theoretical building. We surmise that the emphasis commonly laid on the role of Einstein as opposed to that of other major scientists, in particular Poincaré, shows a degree of bias and of neglect of the historical and textual evidence. Our investigation provides a specific example where this bias can be proven in a rigorous way and traced back to its sources.

The recognition due to Poincaré has been too long obfuscated by a widespread overreaction to Whittaker's chapter on special relativity in his famous history of electromagnetism – "The relativity theory of Poincaré and Lorentz" – (Whittaker 1951–1953, II, pp 27–77). While the reconstruction presented there is in several ways unsatisfactory, the stress on the importance and primacy of Poincaré's contribution (to be more carefully separated from Lorentz's than Whittaker did) is on the whole warranted, and our analysis strengthens it in one point that, curiously, was ignored by both Whittaker and his critics. Just to put the whole debate in the right perspective, we should like to emphasize that both Einstein's and Poincaré's contributions to science have been so remarkable and wide–ranging, that although the priority issue concerning special relativity has much to teach from an epistemological and historical point of view, it is of little consequence as to the determination of their place in the scientific pantheon.[5]

## 4 Conclusion

Finally we think that the case study we have presented is also relevant to contemporary concerns on the assessment of research and researchers through citation counting. In fact historians can help bibliometric scholars, through detailed examples, to reach a proper awareness that citations, and

[5] In particular, as Max Born wrote: "In my opinion [Einstein] would be one of the greatest theoretical physicists of all times even if he had not written a single line on relativity […]" (Schilpp 1970, p 163).

the failure of citing as well, have many, widely different functions, and that in particular they cannot be conceived as evidence for straightforward, objective or even subjective, value judgements.

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# Surveying Methods and Instruments in the Sixth Book of Ieronimo Pico Fonticulano's Treatise on Geometry (1597)

**Mario Centofanti and Stefano Brusaporci**

**Abstract.** Many treatises on geometry were written in the XVI century. Ieronimo Pico Fonticulano (1541–1596) in the sixty book of his treatise titled *Geometria* (1597) describes the surveying instruments and their methodological and operative use. The aim of the paper is studying the instruments described by Fonticulano and, thanks to the numerous applicative examples, analysing the surveying methods. It focuses on instrument's geometry and materials, their components, the using modalities, the instrumental positions, the working principles, the main application allowed. Last but not least instruments and methods are studied in relation to their historical context and to the ones presented in other treatises of the same age.

Key words: History of science, Fonticulano, Surveying instruments, Surveying methods, Geometry

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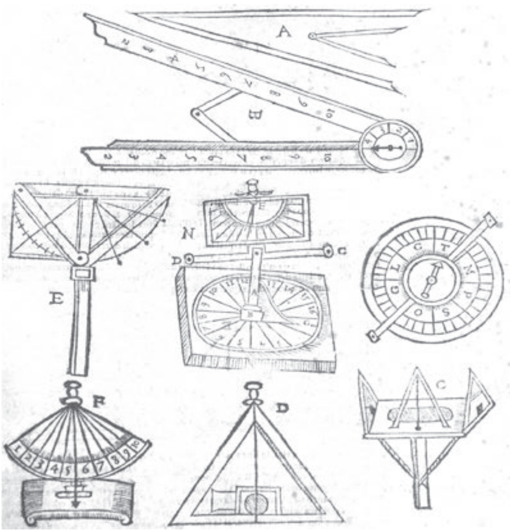
## 1 A Short Introduction

The second half of the sixteenth century is an age of scientific development and knowledge codification. The study of geometry is a tool for architectural design and a method of knowledge. Euclid's *Elements* are the basis of all surveying theories and applications. In particular survey becomes very important because of a deep change in military techniques, especially in reference to the use of firearms. Most of measuring instruments has ancient origins, but only from the half of the sixteenth century treatises on the art of measuring has begun to circulate with some frequency. Their diffusion is facilitated by the development of large printing offices in Venice, Bologna, Rome (Docci and Maestri 1993; Harley and Woodward 1987; Vagnetti 1970).



a) The lame (or mobile) square.
b) The Latin radius with quadrant and altimetry scale.
c) The theodolite.
d) The compass.
e) The artilleryman level.
f) The wind level.
g) The water level.

**Fig. 1** Some instruments described by Fonticulano[1]

Ieronimo Pico Fonticulano (Fontecchio, L'Aquila 1541–Naples 1596) was a mathematician, land–surveyor, cartographer, architect, writer of treatises.

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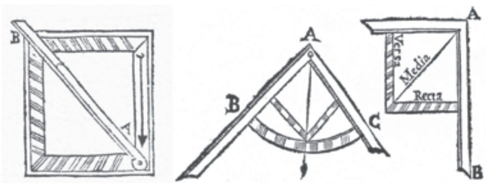
[1] Fonticulano [1597] 2001, folio 213.

He is the author of two printed volumes that can be included between the most interesting treatises of the XVI century: *Geometria*, published posthumous in L'Aquila in 1597, and *Breve descrittione di sette città illustri d'Italia* published in 1582 (Centofanti 2001).




a) The geometric quadrant.
b) The quadrant of the circle
c) The asymmetric square

**Fig. 2** Others instruments described by Fonticulano[2]

## 2 Surveying Fonticulano's Geometry

In the Sixth Book of his treatise on Geometry, Fonticulano describes the surveying instruments of the XVI century (see Fig. 1); many times they are presented with practical case study. In particular Fonticulano treats the following ones.

*The geometric quadrant*. It is an instrument for distance measurement, based on an optical procedure related to the similitude between orthogonal triangles. The quadrant presents graduated sides, plumb and alidade (see Fig. 2a). It requires the collimation of the target with the alidade and the reading of the graduation it indicates on the shared side of the instrument. The measurement is based on the similitude between triangles (see Fig. 3a, triangles ADB and AHC). The quadrant can be also used sighting (i.e. aligning) the not graduated side with the target and the plumb gives the value of the graduation (see Fig. 3b). If the surveyor cannot approach at the base of a tower, he has to realise two measurements, carried out while maintaining the same alignment with the target. Knowing the distance between the two station points, the height of the tower is proportional to the ratio of the station points' distance and the measurements given by the plumbs.

[2] Fonticulano [1597] 2001, folio 212, 215.

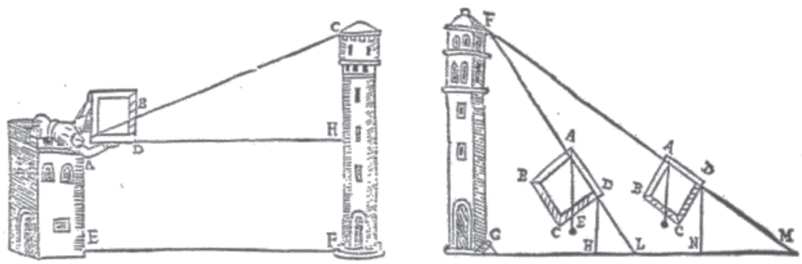


**Fig. 3** The geometric quadrant[3]

A third way of use of the geometric quadrant is described by Fonticulano in two examples about the measurement of the height of an accessible tower (see Fig. 4a, where the plumb is fixed to the alidade) and the height of a tower from an higher one. A fourth arrangement is based on the use of the quadrant without alidade, sighting the target two times from specific and well known station points (see Fig. 4b).

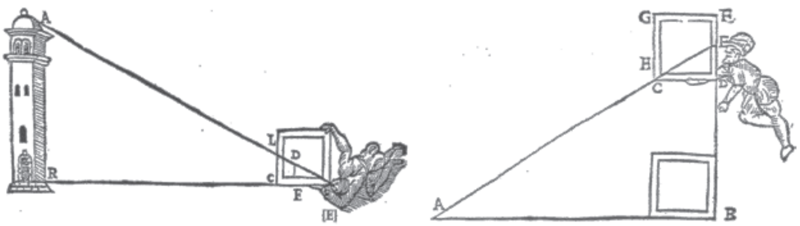


**Fig. 4** Another image of the geometric quadrant[4]

*The quadrant of the circle*. Fonticulano represents not the traditional instrument (Bartoli 1564; Ryff 1548), but a variant of equal use, characterized by sides of different length (see Fig. 2b). The longer side is useful to put it into cannon's mouth to calculate the elevation of artillery shots. The way of use of this instrument is similar to the one of the geometric quadrant.

*The asymmetric square with straight sides*. It is a simplification of the quadrant of the circle, without the quarter of circumference (see Fig. 2c).

*The Latin radius*. Fonticulano describes two kinds of Latin radius: the simple Latin radius with compass and the Latin radius with quadrant and

[3] Fonticulano [1597] 2001, folio 229.

[4] Fonticulano [1597] 2001, folio 221.

altimetry scale (see Fig. 5a and Fig. 1b) (Orsini 1583). It's made of five parts: the *legs*, the *arms* and the handle: arms are hinged together on the top of the handle and each one with a leg; they can rotate around hinges. On the other side legs are hinged together and this point can slide along the handle. A compass is on the bottom of the handle. The geometric principle is always the same: the similitude between similar triangles. An example about the measurement of the distance between two not accessible stronghold allows to describe how to use the Latin radius (see Fig. 5b): the handle must be ever orthogonal to the central point of the castle's walls; the surveyor opens the instrument until FN = DE aligning the targets, then he distances himself from the first station point until HF = FO and, at the same time, a aligns HL with the first stronghold and HM with the second.

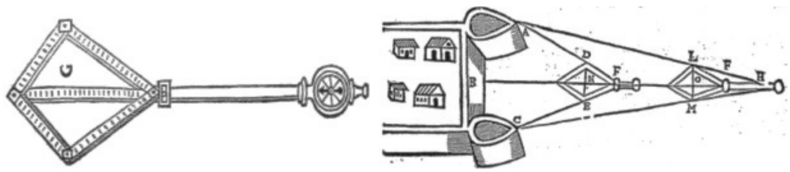


**Fig. 5** The Latin radius[5]

The triangle FDE is similar to FAC and HLM to HAC. Therefore the distance AC between the strongholds is equal to the distance between the two station points.

*The Jacob's staff*. Fonticulano describes it as a stick four or five feet long (i.e. between 1 and 1,30 m), with square section, graduated into six, eight or ten shares. In correspondence of each share an orthogonal stick, two spans long, can be fixed. The Jacob's staff works similarly to the latin radius (see Fig. 6a). Fonticulano presents the same example described for the latin radius, concerning the measurement of the distance between two strongholds (see Fig. 6b).

[5] Fonticulano [1597] 2001, folio 212, 234.

**Fig. 6** The Jacob's staff[6]

*The compass*. It's made by a circular element graduated in 360 shares, with the indication of winds directions, a central compass with an hinged sighted alidade (see Fig. 1d). The surveyor orients it according to the north direction, then he sight the target; he doesn't measure angles but directions and he can record the orientation, or directly represent it on the map**.**

*The lame (or mobile) square*. It's made by two wooden graduated elements hinged together (see Fig. 1a). The arms can be six spans long (i.e. more or less 1,50 m), or one span long. The arms are opened to adhere with the walls, therefore the surveyor doesn't measure the angle but "copy" the directions; then the shorter square is opened according the longer one and it's used to re–drawn the wall's alignments on the map. The square can have a compass fixed on the hinging: it give the possibility to orient the sides according to the cardinal points.

*The theodolite*. It's an instrument that at the same time allows the measurement of distances in all directions and of elevations (see Fig. 1c). It's made by two graduated circles: a vertical semicircle with alidade for zenithal measurements, hinged on an horizontal circle for azimuthal alignments. The two circles are graduated in 16 shares, corresponding to wind directions. The instrument he draws is similar to the *visorio* or *Polimetrum* built by Waldseemuller in 1512 (Waldseemuller 1512).

*The water level*. Fonticulano describes the water level as a wooden instrument made by an horizontal board with a wide central hole, where there is a graduated water tank (See Fig. 1g). The board is hinged on a vertical staff and its gradient can be regulated and fixed by ropes, to level it. On the board there are three plumb–rule.

[6] Fonticulano [1597] 2001, 212, 233.

## 3 Conclusion

Fonticulano shows an expertise and updated knowledge of geometrical principles and applications. Two aspects are of particular interest: many instruments are all based on the same principle of similarity between triangles; the instruments to record corners are not usually used measuring angular dimensions but directions, also in an absolute reference system thanks to a compass. The second consideration it's also suggested by the indications taken from others treatises – for example see La nova scentia by Niccolò Tartaglia (1499?–1557; Tartaglia 1562) – and we know that in the notes of Leonardo da Vinci (1452–1519) for the city of Imola surveying there aren't measures of angles but only of distances (Docci 1987). The aim of Fonticulano is presenting instruments and procedures usefulfor simply and immediate measurements, without complex mathematical operations. So we can consider the Sixth Book a sort of handbook for the resolution of practical, but essential, surveying and military issues.

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# Drawings concerning Artistic Techniques in the Diderot's and D'Alembert's Encyclopaedia

**Emanuela Chiavoni**

**Abstract.** The objective of this paper is to analyse some drawings relating to the artistic techniques in the first volume of the Diderot's Encyclopaedia (1751). The Encyclopaedia is still now considered the laic bible of the century of the lights. It has been selected some of the most significant pictures concerning to drawing, painting, mosaic, sculpture and engraving, showing the rich interconnections between these different kinds of art and the drawing, from whom all of them was born.

Key words: History of scientific drawings, Artistic techniques, Diderot's and D'Alembert's Encyclopaedia

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## 1 A Short Introduction

The volume presents all of the over 2700 plates from the Encyclopaedia, a monument of the technological, artistic and scientific knowledge of the Enlightenment. This vast complex of illustrations is organized by subject, gathered in five large thematic sections, each with an introductory essay. The illustrations are accompanied by historical information to help the reader understand the cultural and social context from which this great work arose. Written in French, the Encyclopaedia (*Encyclopédie ou Dictionnaire raisonné des sciences, des arts et des métiers*), as the first example of a modern Encyclopaedia directed towards a large audience and the inspiration for the structure of those that were to follow, is still considered the *secular Bible of the Age of Reason*. Denis Diderot (1713–1784) directed it from 1746 to 1757 together with the mathematician Jean Baptiste Le Rond D'Alembert (1717–1783) and then completed it on his own, creating a total of twenty–eight volumes, including seventeen of text and eleven of illustrations. This enormous undertaking involved dozens of contributors and around a thousand workers. Before this project, Diderot had already approached the world of science with a translation of Robert James' Medicinal Dictionary, three years of work that taught him how to prepare an Encyclopaedia and stimulated his scientific interests. Diderot maintained that encyclopaedic order was possible only in dictionary form, and above all, that technical and scientific information could thereby be introduced into the corpus of knowledge, abandoning a predominantly literary culture.

The Encyclopaedia covers a host of topics: agriculture, fishing, architecture and construction, artistic techniques, music and musical instruments, writing, books, the sciences, and traditional techniques for working with wood, metals, fabrics, leather, skins, ceramics and glass. These are followed by the first chemical techniques, the passions of the gentleman, military art and the trades of everyday life. This study will analyze the Encyclopaedia's illustrations of artistic techniques presented in the first volume of 1751; to this end, several of the most significant plates dealing with drawing and painting have been selected.

## 2 Drawing and Painting in the Eighteenth Century

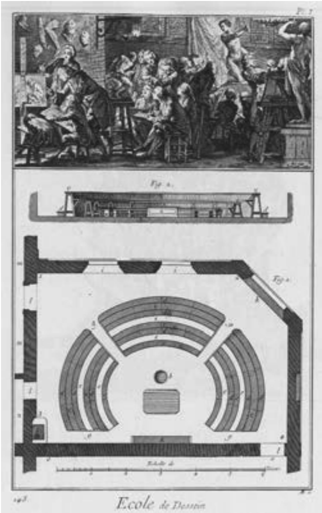
The art of drawing springs from the admiration that men of all times have felt for the spectacle of the universe, from their respect for nature and its products, and from the attempt to reproduce the objects of everyday life or fix people and events in memory. Nature has been and will always be humanity's principle teacher, and drawing is the medium from which all of the arts are born: painting, sculpture and engraving. The Encyclopaedia's remarks on drawing bear witness to the fact that the eighteenth century had begun to see this artistic discipline in the light of its instructional value.
Here, we have moved beyond the teaching that took place almost entirely in the artist's workshop, as was the case until the end of the seventeenth century, although drawing had been the subject of a number of written treatises even in the Middle Ages. For the first time, the teaching of drawing was introduced into school programs, both as an aid to writing and for its practical utility. But the most marked influence on the method of teaching drawing was that exerted by Jean–Jacques Rousseau, who held that drawing should be learned from life, by imitating the originals and not by copying other drawings. In the eighteenth century, a number of pictorial genres were equally in vogue: portraits, still lifes and scenes of everyday life were all responses to the Enlightenment's desire to investigate reality. The scenes of everyday life in particular document the character of eighteenth century society. The paintings of the English illustrator William Hogarth (1697–1764), for example, are intended as social criticism. With bitter humour, the artist portrays the life of the society of his day, exposing its vices and moral corruption.

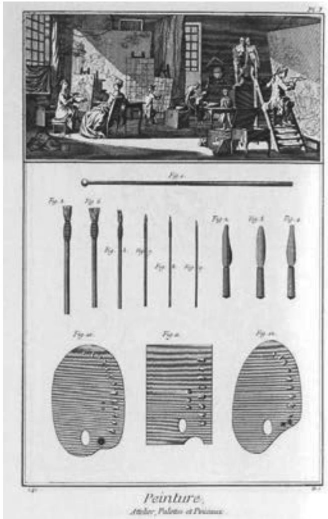
As regards artistic techniques, there was a greater orientation towards the direct method. In other words, colours were for the most part applied directly without particular preparation, though with rational discernment. This was the period that saw the rise of the pastel technique, as the simplest and most direct form of painting. The invention of pastels was long attributed to Alexander Thiele of Erfurt, supposedly at the dawning of the eighteenth century. In reality, however, charcoal drawings were *highlighted* with colour–pencils as early as the sixteenth century in Italy
Classified according to their consistency as soft, semi–soft and hard, pastels are made by mixing powdered pigments with water thickened with an agglutinant binder (gum Arabic or Marseilles soap are typically used). The paste is then shaped into sticks and dried. White clay is added to obtain different hues of the same colour, while Armenian bole is used for

reds and black hematite for dark tones. Preparing pastels is a delicate process, as it is not easy to reduce different materials into malleable paste, but the colour is almost unalterable over time, and adheres to the surface through simple pressure, with dense, velvety effects. While the *French pastellists* of the eighteenth century were celebrated, watercolours were less commonly used. It was only towards the end of the century that the work of English painters (and the contribution of William Turner) raised this technique to the status of a true artistic genre. It should also be emphasized that the regular biennial expositions that promoted encounters between artists and their public and laid the groundwork for modern art criticism began in the eighteenth century.

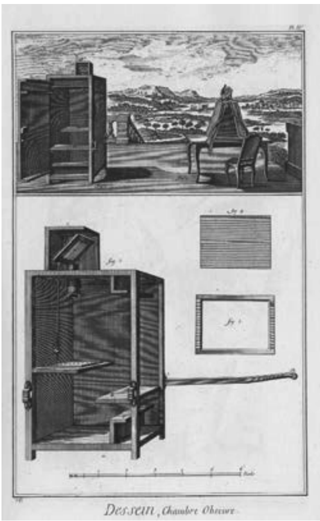
## 3 The Plates Illustrating Artistic Techniques

Much can be learned from a careful analysis of the plates. First, we gain an insight into the tools and specific objects used in that period for the art of drawing and painting, which are minutely described, ordered and catalogued. A second and likewise important aspect of these plates is that they show us the places where these arts were practiced in the 1700s: the classrooms, the ateliers, the workshops are painstakingly described in the plates that depict their spatial conformation and distinguishing characteristics. These areas where students were trained were designed with particular attention to their interior space, and especially to the light from the windows that determined the placement of the furnishings. For example, the plate in Fig. 1 is a view of a school with groups of students of various ages, some not very young, engaged in copying from drawings, plaster casts or directly from life.




**Figs. 1-2** The School of drawings: (l) plan and section of a room for drawing from life; (r) studio and painter's instruments[1]





**Figs. 3-4** The School of drawings: (l) A dark room; (r) The drawer's instruments

[1] Diderot and D'Alembert 1751, plates 143–141. For figures 3-4: *Ibidem*, plates 147–144.

The observer's attention is drawn towards the source of light; the beginning student will have to copy the illuminated part of the model, as drawing the shaded part calls for much more experience and greater mastery of technique. Below this view, the plate shows the classroom's floor plan and section, clarifying the geometry of the space and the light sources to provide fuller information. The arrangement of the desks is also perfectly clear, with the students' observation points all converging towards the centre where the life drawing model was doubtless positioned.
In the plate dealing with painting (Fig. 2) the top section shows an imaginary atelier depicted in perspective, with several painters at work: a portrait painter, a copyist, a miniaturist and a history painter. Below, we find a representation of brushes, painting tools and palettes of different sizes and shapes. The drawing of the atelier clearly communicates the handwork involved in painting, drawing attention to the practical aspects of each activity: the ladder used to paint large surfaces, the chair for the sitter next to the portrait painter, the grid used to check a drawing's proportions. These two plates also show the artists, the men and boys in the act of drawing, but this is not true of all of the illustrations. Such is the case of the plate reproduced in Fig. 3, which illustrates a *camera obscura*; in these versions, the *camera obscura*, whose invention is attributed to Giovan Battista Della Porta (1535–1615) is a portable machine with a mirror that reflects the objects outside it. It is of enormous utility both for the beginner and for the expert painter in reproducing exactly what he sees and in perfecting his art. In landscape painting, it can at times be advantageous in representing objects as they are found in nature. The upper part of the plate shows a drawing of a *camera obscura* positioned for use outdoors, while the apparatus and its parts are shown in minute detail below.

As can be seen from the illustration of drawing implements Fig. 4, each instrument and all of its parts are carefully detailed; pens, quills, bowls and an adjustable stool, a portfolio for drawings and even the frame used to check the image in the field of view when drawing outdoors. The picture is like a window onto space and is the cross–section of the visual pyramid that culminates in the viewpoint. It is to Leon Battista Alberti (1404–1472) that we owe the invention of the transparent screen or *veil* marked with a grid, which placed between the scene and the painter intersects the pyramid and transfers it proportionally into the picture. The subjects illustrated in the plates cover a broad range: we find the pantograph, an instrument for enlarging drawings that was widely used in the period by painters and draftsman, as well as the representation of a tree, where the landscape in the background is taken from a pen drawing by Titian. There are also several drawings dealing with the rules of perspective that illustrate the geometric basis for understanding space and representing it in two dimensions. It is clear that perspective is considered to be one of the two principal sciences that are necessary for drawing, the other being anatomy, which is essential for representing the human figure. This section of the work was supervised by Charles–Nicolas Cochin (1715–1790) who also did several of the illustrations reproduced in the text.

## 4 Conclusion

The Encyclopaedia's contribution is important not only from the purely graphic standpoint, but also as regards measurement operations. The illustrations show a mastery of surveying technique, not just for small objects, but for large spaces as well, as is also demonstrated by the metric scale placed with care at the bottom of each plate. Also evident in this work is the sophisticated use of line drawing techniques. Using India ink in lines of clearly recognizable and carefully differentiated thicknesses results in a visual language that can communicate the subjects it depicts objectively and effectively.

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# A Social Mechanics: from Leibniz to Pareto

## Vincenzo Cioci and Antonino Drago

**Abstract.** This work suggests in a parallel way to mechanical laws a series of social *laws* concerning the social conflict; a high level of development of this subject is recognised by collecting several contributions. The first laws derive from the social meaning that Leibniz attributed to the impact of elastic bodies. Later, the great strategist Lazare Carnot who compared the defence of strongholds and mechanical machines suggested some more laws. In 1910 Spiru Haret (1851–1912) wrote *Mécanique sociale* (Haret 1910) a handbook on these laws and Pareto tried to formalise the individual's behaviour inside a market through the principle of virtual displacements.

Key words: Mechanical laws as social laws, Leibniz, Lazare Carnot, Haret, Pareto, Ophelimity

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## 1 Leibniz's Analogy between the Impact of Bodies and Social Relationships

Gideon Freudenthal recently suggested a metaphor of the entire Newton's mechanics as representing the social behaviour of the 17th Century English individual, as subject to the social environment (Freudenthal 1986). He ignored Gottfried Wilhelm von Leibniz (1646–1716), who planned a complete analogy between mechanics and soul's motions (Leibniz 1671). Moreover, he, being a diplomat, devoted himself to bring peace at all levels, from the interpersonal relationships till up to the nations and the religions, through a flexibility in his basic attitude; this surely was paralleled to his modeling of the impact of bodies through the bodies which have been conceived as elastic springs (Piro 2002, pp 72–78); in fact he first stated the modern laws for the impact of elastic bodies in their full generality, by including also the law of relativity (of course, in one dimension).

$$V_A - V_B = V_B^{'} - V_A^{'} \tag{1}$$

$$m_A V_A + m_B V_B = m_A V_A^{'} + m_B V_B^{'} \tag{2}$$

$$m_A V_A V_A + m_B V_B V_B = m_A V_A^{'} V_A^{'} + m_B V_B^{'} V_B^{'} \tag{3}$$

where the two bodies *A* and *B* have respectively the velocities $V_A$ and $V_B$, which are primed for referring them to the time after the impact. This theory is basic for a general mechanics' theory where a continuous phenomenon has to be considered as a limit series of discontinuous phenomena (for instance, a continuous force as the limit of jerks). Leibniz's theory of impact of bodies constitutes a metaphor of conflict resolution in the human relationships; it cleverly suggests to associate mechanical aspects with human aspects. Our mind looks for invariants, Leibniz added.[1] In the interpersonal conflict a person with a flexible

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[1] "The opinion that the same quantity of motion is preserved and abides in the concourse of bodies has reigned a long time, and passed as an incontestable axiom among modern philosophers […]. We begin now to be disabused of this opinion, […]. But in this case an inconvenience has arisen, namely, that we have been thrown too far into the other extreme, and do not recognize the conservation of anything absolute which might hold the place of the quantity of motion. But *our*

attitude preserves, nevertheless of the violence a conflict may elicit, some invariants; they may be identified with the basic human rights, first of all the right of both bodies to survive irrespectively of any change; then the rights to which both contribute, e.g. brotherhood, respect for the other, etc. Moreover, his physical theory constituted an alternative to both John Wallis' (1616–1703) and Isaac Newton's (1642–1727) approach, relying on the model of a perfectly hard body, so rigidly preserving its shape to do not bounce. We can interpret in the same vein above Wallis' and Newton's theory of impact phenomena as representing a macho's approach which faces the interpersonal relationships by taking care to preserve his own shape whatsoever violence he produces on the other.

## 2 From Interpersonal Conflict to War: the Strategy of Lazare Carnot

The military language includes a great number of notions pertaining to mechanics – forces, impact, penetration, centre of mass to be shot, balance of power, etc.. They derives from Newton's idealisation of the impact of hard bodies as it is enlarged to a military conception of the inter–groups conflicts. When instead we choose Leibniz's notion of an elastic body a new approach to the collective conflict is derived as his follower Lazare Carnot (1753–1823) did. First of all, according to a flexible attitude, Lazare Carnot's thought that a defence only has to be fought, never a military attack. Moreover, L. Carnot's theory of mechanical machines constituted a blueprint of his celebrated strategy for a defensive war relying on the defence of strongholds. This defensive attitude may add, in order to object protecting the defender from the violence of an attack, a defensive object; in the personal conflicts, a rigid screen; in the national conflicts a stronghold; hence, he added to the usual military work performed by the besieged the civilian work for building the stronghold; since as Carnot puts it, a stronghold obliges the besieger to fight against

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*mind looks for this*, and it is for this reason that I remark that philosophers who do not enter into the profound discussions of mathematicians have difficulty in abandoning an axiom such as this of the quantity of conserved motion without giving themselves another to which they may hold". (Leibniz 1896, pp 657–658). Author's italic.

walls and embankments. He stated that from a dynamical viewpoint “ [...] a stronghold is a machine without an anime” (Carnot L 1823, p xvi), which clearly the garrison is. His theory of mechanical machines obtained the general law of their dynamics as a balance between the input work and the output work, i.e., $W=fvt$ (with obvious meanings of the symbols). In parallel, a stronghold during an attack may be represented by this same balance; the equilibrium is obtained by a besieged by means of an equal work of the besieger: $FVT=fvt$. At the equilibrium, the besieged’s work opposes a greater force than that of besieger, since the latter performs the same work at a greater velocity; hence, one can defend a country, as Carnot puts it, with 10 times lesser soldiers than the soldiers of the invading Army. In Carnot’s times, an innovation in the strategy threatened all strongholds. Vauban invented the strategy step–by–step, i.e. to slowly approach the stronghold with trenches and light defensive tools, till up to achieve a little distance from the wall and then, being in a more favourable position, to launch the decisive attack. The pupil François Arago (1786–1853) discovered that this step–by–step conduct was considered by Carnot in both the political field and the scientific one, as “[...] the displacements by insensible degrees” (Arago 1837, p 540); in both mechanics and Thermodynamics this notion originated the notion of reversibility. Lazare Carnot considered the advantage of the defence inside a stronghold just to have the possibility to perform the collective action in the reversible way. For this reason, he could not concede the same strategy to the violent besieger. In order to contrast a besieger’s step–by–step attack, he suggested breaking it by means of little sorties by a minor part of the garrison (Drago 1990); i.e., to improve the work performed by a machine by means of little pulses from outside.

## 3 Pareto and the Ophelimity

Elsewhere one of us discussed Spiru Haret’s (1851–1912) handbook widely treating the relationships between mechanical laws and social laws (Cioci 2013). We add here the contribution by Vilfredo Pareto (1848–1923). Let us quote from the *Cours d’Economie politique* (Pareto 1896–1897) by Pareto the Table 1. “These analogies have no value as demonstrations of anything. They only serve to clarify certain concepts which must then be submitted to the criterion of experience” (Pareto 1896–1897, § 592, fn. a).

**Table 1** Similarities between the study of a mechanical phenomenon and that of a social one according to Pareto[2]

| Mechanical phenomenon | Social phenomenon |
|---|---|
| Given a certain number of material bodies, we study the relationships of equilibrium and movement among them, making abstraction from other properties. We obtain thus a study of mechanics. | Given a society, we study the relations that the production and exchange of wealth create among human beings, abstracting from other circumstances. We obtain thus a study of political economy. |
| This science of mechanics is divided into two others. | This science of political economy is divided in two others. |
| If we consider material points and inextensible links we obtain a pure science: rational mechanics, which studies, in an abstract way, the equilibrium of forces and motion. | If we consider *homo oeconomicus* acting only in the context of economic forces, we obtain the pure political economy, which studies, in an abstract way, the manifestations of ophelimity. |
| The easiest part is the science of equilibrium. D'Alembert's principle, considering the forces of inertia, allows to reduce the dynamics to a problem of statics. | The only part we are beginning to know well is that dealing with equilibrium. There may be for economic systems a principle similar to D'Alembert's, but our knowledge of the topic is still very imperfect. The theory of economic crises provides, however, an example of a study of economic dynamics. |
| After rational mechanics comes applied mechanics, which approaches a bit closer to reality, considering the elastic bodies, the extensible links, the friction, etc. | After pure political economy comes applied political economy, which is no longer limited to consider only *homo oeconomicus*, but it also considers other beings who approach closer to real man. |
| The real bodies have not only mechanical properties. Physics studies the properties of the phenomenon caused by light, electricity, heat. Chemistry studies other properties. Thermodynamics, thermochemistry, etc.. deal more particularly with certain classes of property. All these sciences are the physical–chemical sciences. | Men have also further characteristics that are the object of study for special sciences, such as the sciences of law, religion, ethics, intellectual development, aesthetics, organization of society, etc.. [...] Taken together as a whole they constitute the social science. |

[2] Pareto 1896–1897, §592 fn. a.

Pareto's theory is based on the analogy between the mechanical potential energy and ophelimity, i.e. the abstract quality of the things that "satisfy a need or a desire, legitimate or not" (Pareto 1896–1897, § 5). When it exists, ophelimity is the function whose partial derivatives represents the forces $\varphi_k$ (said marginal ophelimities) that motivate the consumption $r_k$ of individual goods $x_k$. Thus, the role played by the forces in mechanics is held by the manifestations of ophelimity in economics. The economic equations of general equilibrium, written for the first time by Léon Walras (1834–1910) in terms of prices, traded goods and ophelimity (called by Walras *utility*), are related by Pareto to the mechanical principle of virtual displacements (Pareto 1896–1897, § 59 fn. b, §144 fn. 1; Donzelli 1997, p 131). In order to pass from statics to dynamics in economics, Pareto tried to find a principle of the dynamical equilibrium in economics similar to that of Jean Baptiste Le Rond d'Alembert (1717–1783) in mechanics. According to Pareto, in economics, the principle of d'Alembert, combined with the principle of virtual displacements, takes the following form which is analogous to the Lagrangian equation:

$$\left(\varphi_a - \frac{\partial x_a}{\partial r_a}\right)\delta r_a + \left(\varphi_b - \frac{\partial x_b}{\partial r_b}\right)\delta r_b + \ldots = 0 \tag{4}$$

The functions $\partial x_k/\partial r_k$ correspond in mechanics to the forces of inertia $md^2r_k/dt^2$, but in economics, according to Pareto, "[…] we ignore the very nature of the functions $\partial x_k/\partial r_k$" (Pareto 1896–1897, §586 fn. a). Later Pareto argued that it was not possible to deduce from the experience the measure of ophelimity but that it was possible to obtain *experimentally* only the equations of indifference curves along which total ophelimity remains constant regardless of the amount of economic goods owned by an individual (Pareto 1936, p 499):

$$\Phi(x, y) = const \tag{5}$$

By differentiating we get

$$\Phi_x(x, y)dx + \Phi_y(x, y)dy = 0 \tag{6}$$

that can also be considered the differential equation for the level lines (See Eq. 5). However, Vito Volterra (1860–1940) objected that the differential form (See Eq. 6) in more than two variables may not admit integral factors and hence the form is not integrable (Volterra 1906, p 300). Afterwards, despite Pareto could not complete his program to link mechanics, as it is expressed in the highest formal levels, to human behavior in a market, he always tried to apply the analytic–synthetic method of science to the study of society as a whole. According to him

> Rational mechanics, when it reduces the bodies to mere material points, and pure economics, when it reduces real men to *homo oeconomicus*, make use of abstractions perfectly similar and imposed by similar necessities. [...]. When you return from the abstract to the concrete, you should again bring together the parties that for the purpose of study you have separated. Science is essentially analytic, practice is essentially synthetic.[3]

## 4 Conclusion

There may be reciprocal enrichment between social analysis and construction of physical theories. At least in principle, physical-mathematical methods of classical mechanics can be applied to economics and social sciences. Taking into account Haret's work connected to this study, we can say that even more than in physics, also in economics and sociology we can make relevant advancements in developing a theory.

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# Notes on Historiography of Engineering in Italy during the 20th Century

**Salvatore D'Agostino**

**Abstract.** The great world of Engineering has outbursted in its all different aspects, from university education to technological and industrial development, both civil and mechanical engineering, as well as electrical and chemical, aerospace and computer science. Due to major concentration on research and innovation, projection toward an inexhaustible technological development affecting relevant and everlasting changing of everyday life, *history* has been neglected. These continuous changings lead to an overgrowing disorientation and suspicion among people since technical and scientific culture is unprepared to face political and social demand of an historical period in which regressive tendencies against scientific progress arise.

Key words: Engineering, Historiograpy, Schools, Italy

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## 1 An Outline

The engineering, which rules technological development and scientific effects on society, must reach more critical consciousness as result of historical knowledge. On these basis Italian engineering, recently has promoted relevant efforts in order to develop a deeper knowledge of its own history. The history of engineering has its origins in the treatises of the sixteenth century. The following excursus, however, starts from the last century, in order to be brief and to the point.

## 2 Notes on Milano's School

Beyond the monumental work by Singer on the history of technology from the origins to today, the more concise history of engineering by Finch also had a certain circulation in Italy (Finch 1962), as has the *Storia dell'Industria Europea*, (AAVV 1981): an important series of essays illustrating the development of industry in Europe from the *Industrial Revolution* to the present. A first significant overview of the role of science in Italy's industrial development appeared in the *Storia d'Italia* (Einaudi). Maiocchi showed the difficulty with which a genuine technical and professional culture made headway, in spite of the contributions of several outstanding figures (Maiocchi 1980). Engineering still lacked an identity of its own with respect to scientific evolution and industrial development. The tenth volume of this History, dealing with the Annals and devoted to the leading professionals, features several illuminating contributions. One of them concerns the statistics of growth among students and professions, including the profession of engineer, from 1861 to 1993 (Cammelli, Di Francia 1996). Another one considers the evolution of engineering from the Napoleonic age up to the fascist period (Minesso 1996), and a third one describes the evolution of the new engineer from 1923 to 1961 (Calcagno 1996). Referring once again to the recent volume 26, the essay on *Scienziati e potere politico* (Montaldo 2011) highlights the significant contribution that engineers made to Italian political life and government between the Unification of Italy and the advent of Fascism. Two other essays worthy of citation in the same volume are those by (Ferraresi 2011), illustrating the evolution in the education of engineers from the Unification of Italy to the beginning of the $20^{th}$ century, and by (Pogliano 2011), describing the emergence of *Cybernetics and Information Technology*.

One particular aspect treated is the history of Engineering Faculties in Italy, that, have been abolished. The volume on the history of the Milan Polytechnic dates from 1941 (Lori 1941). It is organised in three parts, the first featuring the life of the Polytechnic from its foundation in 1863 and covers its various locations. The second describes the various scientific institutes, recording the staff, subjects taught and statistics on student numbers. The third is a compendium of documents and official speeches. To mark the hundredth anniversary of its foundation a fourth volume was produced (AAVV 1964) that opens with a long essay on the formation and position of the engineer and architect in the various historical periods. This is followed by a series of essays which illustrate the life and institutions of the Polytechnic both in general and in its twin faculties of Engineering and Architecture. The Turin Polytechnic also brought out a volume on its history from the origins to the eve of the Second World War (Pugno 1959), organised along the lines of the first book produced by the Milan Polytechnic.

## 3 Notes on Roma, Napoli and Bari's Schools

*Dalla Scuola d'Ingegneria alla Facoltà d'Ingegneria di Roma* is a valuable publication by Di Gioia (Di Gioia 1985) tracing the progress from the old School set up by Pope Pio VII in 1817 to the new Faculty. The transfer of the Faculty of Engineering in Naples from its original premises in the historical centre to the new complex in Fuorigrotta was the occasion for a large volume featuring the School of Engineering from 1811 to 1967 (Russo 1967). The first chapter profiles the engineers and architects active in Naples in the 16th to 18th centuries. Then it features the history of the first School of application for the engineers of *ponti e strade* (bridges and roads), founded in Naples in 1811 by Joachim Murat, modelled on the *École des Ponts et Chaussées* in Paris. Then comes the reconstruction of the Royal School of application and its subsequent developments through to the foundation of the Faculty in 1923. It concludes with the history of the Faculty up until 1967, with the inauguration of the new premises and considerations on the function of the School of Engineering in Southern Italy. In 1823 Duke Francesco IV set up a Polytechnic in the Estense duchy. The brief history of this institution has been narrated by Elisabetta Frascaroli (Frascaroli 1998). The history of the School of Engineering in Genoa has recently been published in a series of slim volumes featuring chemical, civil, electronic, mechanical and naval engineering (AAVV 2004). The proceedings of the conference held to commemorate Antonio Lepschy narrate 80 years in the history of the Faculty of Engineering in the University of Padua (AAVV 2006). There is an account of the history of the Faculty of Engineering in Palermo in a publication of the *Conferenza dei Presidi di Ingegneria* reporting a study day held in Palermo on 27 January 2006 to mark the bicentenary of the foundation of the University of Palermo (Cardone, La Mantia 2006). In addition to placing on record their histories, many Faculties have sponsored particular initiatives. The Turin Polytechnic set up the CEMED (Marchis 2006), an outstanding figure in the history of engineering. The Milan Polytechnic created the fine series of 3 publications called *scintille*: five recipients of a *laurea ad honorem* in industrial design (AAVV 2001), the historical collections of the *Department of Eletrical Engineering* (AAVV 2002), and the links between the history of the Polytechnic and that of Italy as a nation, with biographies of the engineers and architects responsible for major innovations (AAVV 2005).

In Naples the exhibition Scienziati–Artisti was organized in 2003, illustrating the formation and role of engineers using materials in the State Archives and Faculty of Engineering (Buccaro and De Mattia 2003) and the parallel conference *From the School of Application to the Faculty of Engineering, Neapolitan culture in the evolution of science and instruction in building* (Buccaro and D'Agostino 2003). Also in Naples, work has recently been completed on the cataloguing of the precious collection of old books, featuring some 4000 works dating from the 17th–19th centuries. These books now occupy their own room in the Faculty library, and some have been reviewed by Faculty members (Buccaro and Maglio 2012).

The Faculty of Bari has promoted a number of lectures on the history of engineering (Cavallone 1994, Bondi 1995, Sollazzo 1995, Cavallone 1996, Monaco 1994–1997). In 2005 the Faculty of Bologna organized fifty or so lectures given by historians and philosophers of science, mathematicians, physicists, chemists and engineers. The lectures are published in the fine volume *Scienza e Tecnica nel settecento e nell'ottocento,* la Rivoluzione industriale vista dagli ingegneri (Mesini and Mirri 2012). In addition there have been a large number of studies by individual scholars on topics relating to engineering, starting from the ancients (Portoghesi 1981; Rossi Rossi, Russo and Russo F 2009) and including *Storia delle macchine: tre millenni di cultura technologica* (Marchis 1994). Other contributions have concerned such fundamental subjects as hydraulics (Pulci Doria 1983) and

Building Science and its historical development (Benvenuto 1981; Capecchi and Ruta 2011) as well as specific aspects (Becchi and Foce 2002). A rich series of volumes illustrating the history of mechanical science and mechanisms has been edited by Marco Ceccarelli, University of Cassino, for Springer (Rovida 2013), together with international symposiums (Ceccarelli 2004). There are also studies featuring notable individuals such as the volume on Luis Escrivà, military engineer in the Kingdom of Naples, (Cardone 2003) and the fine volume on Alessandro Volta and the tributes he received from the University of Pavia in 1878 (Cantoni and Morando 2011).

Other contributions have come from historians who are not engineers. One fundamental work is that of Franco Strazzullo on Neapolitan architects and engineers in the 16th to 18th centuries, published in 1969 and recently reissued (Strazzullo 2010). Another important volume was dedicated to the architects and engineers active in Bologna from 1850 to 1950 in the construction sphere (Gresleri and Massaretti 2001).[1] While this review of the literature makes no claim to being comprehensive, as we said, it is surely indicative of the many contributions that have enriched the history of engineering.

## 4 Conclusion

In view of the cultural, social and political difficulties of this moment, which are hardly favourable to a technical and scientific culture critically aware of the complex requisites imposed on it, it is necessary to identify some national points of reference that can enable the history of engineering to be systematized, with the widespread involvement of engineers and their institutions. In this perspective the *Conferenza dei Presidi delle Facoltà d'Ingegneria* launched the important initiative of a series of publications illustrating the history of individual sectors. Until today date two have been published, featuring the history of electrical engineering (Cantoni and Silvestri 2009; Silvestri 2002) and that of telecommunications in Italy (Cantoni, Falciasecca and Pelosi 2011; Cantoni and Morando 2011 et succ.). In 2004 the *Associazione Italiana di Storia dell'Ingegneria* (AISI) was founded in Naples, with national congresses held every two years.

[1] In addition we can mention Di Leo 2006; Ferraresi 2004; Bianco 2000.

This initiative mobilises interest in the history of a vast spectrum of engineers with the most diverse backgrounds. Under the aegis of the Consiglio Nationale and Ordini Provinciali degli Ingegneri in Naples and Salerno, it has attracted considerable attention. The eight volumes with the Proceedings of the four Congresses held to date (Buccaro 2006, D'Agostino 2008, 2010, 2012) run to over 5000 pages, distributed to all the Ordini Provinciali in Italy, and accessible on the website: www.aising.it. In addition the Association has begun publication of an on line bulletin on its website. Regrettably the Faculties rejected the invitation to introduce courses in the History of Engineering, which would have guided students not only to an understanding of their past but also to envisage the trends in the future for the relationship between engineering and society. Likewise, although the Ordini Professionali participate actively in the biennial Congresses, they have not inserted the history of engineering in their multiple activities, which remain restricted to an arid conception of technical and professional updating.

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# Tito Gonnella's Planimeter

## Alessandra d'Amico Finardi

**Abstract.** The planimeters are area measuring tools. Now they are precision instruments used to trace around a closed loop of an object to find its area. The planimeters are used by engineers, surveyors, contractors, designers, and more. There are many kinds of planimeters, but principally roller and polar planimeters were introduced and used. The Swiss mathematician Jakob Amsler–Laffon (1823–1912) built the first modern planimeter in 1854, the concept having been pioneered by Johann Martin Hermann (1785?–1841) in 1814 and by Tito Gonnella (1794–1867) in 1824. In this paper I will present Gonnella's planimeter and its peculiarities

Key words: Area measuring tools, Planimeter, Tito Gonnella

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## 1 A Short Introduction

It is impossible to accurately determine with geometric procedures the area of a surface whose perimeter is an irregular curve line. The problem, however, was particularly felt ever since ancient times, especially in the world of surveyors, who often had to measure lands that had shapes of this kind. Il was necessary to resort to empirical methods, by roughly breaking the figure into regular polygons, or by drawing it on a rest which was then weighed. These systems were very inaccurate, slow, and very cumbersome. In the eighteenth century and in the first half of the nineteenth century, several machine which partly automatized them were invented, by making calculations, of not more accurate, at least faster (Zobel's, Oldenburg's and Beuvière's planimeters). But only then the idea come of applying the integral calculus to the problem, was it possible to build planimeters based on scientific principles.

## 2 A History

The first planimeter of this type was built by Johann Martin Hermann in 1814. This planimeter however, is known to us only through a later evidence (Bauernfeind 1855) and two original drawings which fortunately came to us. A few years later, in 1824, the Tuscan mathematician Tito Gonnella (1794–1867) showed a *squaring machine* he had invented to some colleagues in Florence, to Count Vittorio Fossombroni (1754–1844), state secretary, to Guglielmo Libri Carucci dalla Sommaja (1803–1869) a member of the *Institut de France*, and shortly afterwards to Leopold II as well, who immediately asked him to build a second identical machine for his own mathematics studio.

## 3 Gonnella's Life and Inventions

Tito Gonnella was born in Livorno. Professor of Mathematics and Mechanics at the *Accademia di Belle Arti* in Florence, he linked his name to several inventions, including an improvement of the reflecting telescope in 1841, and two mechanical calculators described in the book *Descrizione di due machine aritmetiche per l'addizione*. The *squaring machine* was a planimeter, in its first version not so different from Hermann's one. Later

Gonnella built a second improved version which was shown at the Great Exhibition in London in 1851 and which won him the top prize in the category, the Council Medal. Gonnella described his invention in an article on *Antologia* in 1825, which is therefore the first published paper where the planimeter is mentioned. The second version of the planimeter is described in *Opuscoli matematici* in 1841. Both of these articles which were published in Italian, the latter one by a local printer, probably in few copies, had a very limited circulation. In 1873, an article by Antonio Favaro, the famous curator of Galileo's National Edition, drew upon them the attention of the scientific world. In the meantime, however, some scholars had come to learn about Gonnella's machine in other ways. In an article dated 1894, Olaus Magnus Friedrich Erdmann Henrici (1840–1918) wrote:

> Gonnella had one instrument made, but it seems he was unable from the want of skilled labour in Florence to obtain a well executed piece of mechanism. When the Archduke of Tuscany wished to add a well made planimeter to his collection, Gonnella looked for its execution to Switzerland, where the flourishing watch industry had developed accurate workmanship. He accordingly sent, in 1825 and 1826, through a Florence merchant, numbers of drawings to different firms in Switzerland, without, however, succeeding in getting what he wanted. In 1826 the Swiss engineer Oppikofer invented a planimeter, and this was made in the following year. How much he had heard of Gonnella's invention or of Hermann's cannot now be decided. It is, of course, quite possible that he should have made an independent discovery. Bauernfeind estimates that at that time about a billion areas had annually to be evaluated in Europe. He also gives in the paper quoted a pretty long list of various contrivances for facilitating this work, and which, by the way, were called planimeters (they were not integrators). The problem was, therefore, one that pressed for a solution, and it would be quite in conformity with other instances in the history of science that several men should perfectly independently make the same invention. Nevertheless, there is a possibility if not probability that Oppikofer should have heard of Gonnella's invention. Anyhow, it is his instrument which became the starting–point of the further development of planimeters. Oppikofer, it seems, put himself in communication with the mechanician Ernst in Paris (before 1836) to introduce the instrument in France. Thus it come that planimeters of type I. are known in France by the name of Ernst, who

improved them and made them practical instruments. He retained the wheel rolling on a cone, although Gonnella had already in 1825 replaced the cone by a horizontal disk.[1]

## 4 Gonnella's Planimeter

It isn't possible to claim that, once Gonnella's drawings arrived in Switzerland, they may have suggested building similar planimeters. Ever since 1825 we have definitely seen a true proliferation of more and more planimeters, essentially operating on Hermann's and Gonnella's principles. It should be said, for the sake of impartiality, that these principles were quite simple and obvious: in 1826 it was very difficult, on the other hand, to build the inherently complex instrument, with mechanisms that must operate with great precision and low friction, two qualities hardly compatible with one another. In 1825 Gonnella describes his invention as follows:

> To have an idea, if not about all, at least of the main pieces that make up the present machine, imagine a smooth metal ruler flowing horizontally in the direction of its length over two pulleys and bearing – fixed above itself in a frame an axis or a vertical cylinder finished in two conical tips rotating in two holes. The bottom of this axis is shaped as a sprocket and the upper part carries a flat or circular disk, which runs horizontally through the rotation of the spool or the axis itself. The rotation is then exerted on the spool by a toothed horizontal ruler which engages, always producing a right angle, with the smooth ruler. To the end of the toothed line/ruler the tip P is fixed: this is due to go through the perimeter of the figures to be squared. Another part of the machine not depending on the described system of pieces, and that during the action of the above machine never suffers any translational motion, is a horizontal rotating axis that at one end is carrying a R wheel, those periphery normally poses and gravitates on the floor of the previous disk, having the point of contact on the same diameter of the disk which is parallel to the smooth line, so that with the progressive motion of this center of the disk it would pass under the point of contact of the wheel. At the other end of this axis of rotation a pointer is fixed perpendicularly to the same, the top of which runs on the turning of the axis a fixed dial vertically graduated, and

[1] Henrici 1894, p 506.

> it marks on this the smallest motions of the rotation on the R wheel, magnified. This extreme point of the needle running the circumference of the dial is the point Q shown on page 123. The R wheel which gravitates as we said before on the horizontal plane of the disk is forced to rotate due to the friction force whenever the disk rotates with the same sprocket wheel.[2]

We found no trace of the original machine illustrated in the 1851 London Exhibition catalogue, which points it as belonging to the grand Duke of Tuscany. The drawing corresponds to the planimeter described in the article in the *Antologia* quite well. However, some differences are to be underlined. In the text the horizontal line carrying the tracer tip is defined as *toothed* and it engages in a sprocket placed on the axis of the horizontal wheel. This way it's clear that the longitudinal movement of the line turns the wheel now in one direction, then in another. From the drawing, it is evident that the rack–pinion system has been replaced by a single wire, integral with the row, winding around a smooth spool: it is a much more primitive kinematic, that is subject to breakage or slippage, which was probably adapted because of the difficulty of building such a long toothed row, connected to the axis of the wheel without play to the pinion.

## 5 Gonnella's Planimeter Peculiarities

Compared to Hermann's planimeter, Gonnella's planimeter has two important differences. Fist of all, the cone was replaced by a disk. From the mathematical point of view, it is irrelevant, as a disk is simply a cone with a zero vertex angle. From the constructive point of view, it is relevant, because a disk is much easier to be manufactured and it occupies a much smaller place. In addition, from Gonnella's solution the disk planimeter or *Scheibenplanimeter* is derived, which will be rediscovered several years later, an it will be a class of instruments apart, because of their precision. It should also be noted that in Hermann's planimeter the longitudinal movement of the line to which the tip is integral ($y$ axis) lets the wheel slide along the side of the cone, while the transversal movement

[2] Gonnella 1825, p 125.

of the whole system (*x* axis) sets the disk in rotation. In Gonnella's planimeter it is exactly the opposite.
Gonnella's machine was carefully examined and discussed during a meeting of Italian scientists held in Florence in September 1841. In the 29$^{th}$ September meeting professors Doveri and Massotti, previously appointed by the board to examine the machine, read a very reliable and detailed report, that in many ways completes Gonnella's article appeared in *Antologia* some years before. Note that by this date both the machine and the *Opuscoli matematici*, published the same year, were available. The two speakers than declare not to submit a description of the machine, because it can be found in the *Opuscoli matematici* recently published, and since the machine *may be found* in the Grand Duke's laboratory.

## 6 Conclusion

The report tells us, however, some interesting things. First of all, that the machine physically existed and that it was possible to see it at the Grand Duke's laboratory. Than, that Gonnella's first idea involved the use of a cone, and only at a later time did he think of the disk. Indeed, in *Opuscoli matematici*, Gonnella shows that instead of the cone or the disk you can use as *main piece* the solid formed from the revolution of an *equilateral hyperbola* around the asymptotes. Finally the Grand Duke's machine probably had a rack and a pinion; unfortunately we do not know who manufactured them.

The report, however, makes us think the machine did not work perfectly, especially because of its mechanical complexity and the technological limitations of time: if we wonted to rebuild it today, the use of bearing would probably be sufficient to assure far greater accuracy and fluency.

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# The Dualism Wave–Particle and Principle of Relativity

**Pietro Di Mauro**

**Abstract.** *Is it compatible the de Broglie's relation with the principle of relativity?* A few reflections and ideas to put together the principle of relativity, foundation of classic and relativistic physics, and the wave–particle dualism, basis of quantum mechanics.

Key words: Dualism wave –particle, Relativity, Landé, de Broglie's relations

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## 1 A Short Introduction

Alfred Landé (1888–1975) remarked (Landé 1975, p 702) that the following de Louis–Victor–Pierre–Raymond (7th *duc*, so called) de Broglie's (1892–1987) relation

$$p = \frac{h}{\lambda} \tag{1}$$

is not covariant with the principle of relativity: the *momentum* of a particle changes if measured in another system that moves relative to the first translational motion with uniform speed *u* (we always consider it, for simplicity, positive), while the wavelength – associated with de Broglie's relation – should not change. Landé wrote that "*A snapshot of ocean waves taken from a lighthouse displays the same wavelength as one taken from an airplane*"[1] In the two systems it would be $\lambda' = \lambda$ and

$$p' = p + mu \tag{2}$$

That is incompatible with de Broglie's relation because there should be even $p' = p$, given that $\frac{h}{\lambda'} = \frac{h}{\lambda}$. That is:

> In the *nonrelastivistic domain*, the relation $\lambda = h/p$ violates one of the most sacred postulates of theoretical physics, that of *covariance*: whereas a momentum $p=mv$ of particle in a system *O* changes to $p' = p + mu$ in a system *O*' moving with velocity *u* relative to *O*, a wavelength λ remains unchanged, $\lambda' = \lambda$.[2]

[1] Landé 1975, p 702. (Author's italic). See also 1971, p 222.
[2] *Ibidem*.

## 2 Some Considerations and Ideas

In the context of relativistic paradigm in which, however, de Broglie's relation was deduced (as in the following) one would get the same by using the formulas provided by special relativity. In this case we have to take account new definition of the *momentum* and but we should consider, consistently, the so–called contraction of lengths applied to the wavelength and the relativistic rule of speed addition. Thus

$$p = \gamma m_0 v = \frac{h}{\lambda} \tag{3}$$

and still one should write even

$$\lambda' = \frac{\lambda}{\gamma'} \tag{4}$$

being $\gamma' = \frac{W}{\sqrt{1 - W^2/c^2}}$ with $W = \frac{v + u}{1 + v \cdot u/c^2}$. By following the same proceedings as before, for the other system we would have:

$$p' = \gamma' m_0 W \tag{5}$$

united to another expression given by

$$p' = \frac{h}{\lambda'} = \frac{\gamma' \cdot h}{\lambda} = \gamma' \cdot p \tag{6}$$

Substituting the used relationships we obtain

$$m_0 W = p \tag{7}$$

valid for only one value $u = \frac{v(\gamma - 1)}{1 - v^2 \cdot \gamma/c^2}$.

In my earlier work on the de Broglie's relation (Di Mauro 2008), I pointed out some difficulties in the derivation of the same as in the experimental verification of what it is believed to be the relationship that has extended the dual wave – particle also matter. Equality $h\nu_0=m_0c^2$ on the basis of the de Broglie's relation, a synthesis of the two major theories that emerged in the science of the last century, I pointed out that it is just incompatible with special relativity: for a particle in motion by increasing speed also the energy and the frequency should increase against time dilation, inverse of the frequency, predicted by Einsteinian theory! Furthermore it brings with it another inconsistency. In his Nobel Lecture de Broglie derives his famous relation simply by equalities (de Broglie 1929, p 247)

$$p = \gamma m_0 v = \frac{h\nu}{c^2} v = \frac{h\nu}{V} = \frac{h}{\lambda} \tag{8}$$

By using the concept, all relativistic, of *total energy* $E=\gamma m_0c^2$ of the particles (with $\gamma$ as usual Lorentzian factor $\left(\left(1-v^2/c^2\right)^{-1/2} = \left(1-\beta^2\right)^{-1/2}\right)$ and, in this case, also the wave phenomenon associated with them. But, while the amount of motion for a particle at rest, as regards to a certain observer, is nothing, and this would lead to a wavelength of de Broglie tending to infinity, its total energy is different from zero being still valid $E=m_0c^2$. This would lead to even associate a wave to a stopped particle, against precisely de Broglie's relation. If we use in the deduction made by de Broglie instead of total energy the kinetic one in the Planck–Einstein's relation $h\nu=m_0c^2\,(\gamma-1)$ (which is zero if it is the *momentum*) we would obtain, following the same steps (Di Mauro 2008, p 70) and instead of the de Broglie's relation, the following equality:

$$p = \frac{h}{\lambda} + m_0 v \tag{9}$$

Clearly, if the relationship could be considered a new definition of *momentum* which contains the two corpuscular and wavelike aspects, then it would be covariant according to what specified by Landé (Landé 1971, p 222, 1975, p 702), with the principle of relativity, and assuming $\lambda' = \lambda$.

In fact we will have:

$$p' = \frac{h}{\lambda'} + m(v+u) = \frac{h}{\lambda} + mv + mu = p + mu \tag{10}$$

i.e. the Equation (2). Nevertheless how it was exactly obtained, being $p = \gamma m_0 v$, i.e. the so–called relativistic *momentum*, it should be stated, first of all, that the relativistic increase, compared to the classical *momentum* , is given just by the wavelike aspect supplied by the term containing the length of wave. By the same procedure done previously for de Broglie's relation and using the same symbols with the same definitions as before, we can write

$$\begin{cases} p = \dfrac{h}{\lambda} + m_0 v \\ p' = \dfrac{\gamma' \cdot h}{\lambda} + m_0 W \end{cases} \tag{11}$$

It is only possible for $W - W\sqrt{1 - W^2/c^2}$ given! Coherently with de Broglie's ideas we can define the frequency of the wave associated with a moving particle as

$$\nu = \frac{c^2}{\lambda \cdot v} = \frac{V}{\lambda} \tag{12}$$

We try to find out how the defined frequency changes when the particle is observed in the motion system with velocity u as regards to the system fixed to the particle. In other words, we have to consider a kind of Doppler effect also for the waves associated with particles. We need, meanwhile, to take account of how the kinetic energy varies in a reference system in uniform translatory motion as to the integral one with the particle. This shows a problem. The kinetic energy supplied to a body by some force in a certain reference system becomes larger when measured according to another reference system in uniform translatory motion as to the first without having, indeed, an increase in the work done by force.

In fact, using the classical expression of the kinetic energy we have:

$$E' = E + p \cdot u + \frac{1}{2} m_0 u^2 \tag{13}$$

while with the relativistic assumption, we obtain:

$$E' = E \frac{\gamma' - 1}{\gamma - 1} \tag{14}$$

Similarly, for the total energy it occurs that

$$E' = E \frac{\gamma'}{\gamma} \tag{15}$$

The frequency measured in the moving system must satisfy the definition given before Equation (12), and we can write likewise

$$\nu' = \frac{c^2}{\lambda' \cdot W} \tag{16}$$

It must immediately be noted that by these definitions the wavelength cannot remain unchanged because with increasing speed $v$ the frequency decreases, against just what one would expect from a similar Doppler effect for the waves associated with particles. However, by replacing therein the de Broglie's relation is obtained

$$\nu = \frac{\gamma m_0 c^2}{h} \tag{17}$$

(which is the starting point in the deduction of de Broglie) and we have

$$\nu' = \frac{\gamma' m_0 c^2}{h} \tag{18}$$

Instead, if we were to use the kinetic energy, with the *momentum* given by Equation (7), we would have

$$\nu = \frac{m_0 c^2 (\gamma - 1)}{h} \text{ and } \nu' = \frac{m_0 c^2 (\gamma' - 1)}{h}. \tag{19}$$

Thus, we have

$$\nu' = \nu \frac{\gamma'}{\gamma} \text{ and } \nu' = \nu \frac{\gamma' - 1}{\gamma - 1} \tag{20}$$

by comparing them respectively to the two forms of energy considered. Replacing them in the definition of a given frequency, and taking into account the relativistic contraction of the wavelength, we obtain in the first case

$$W = \gamma v \text{ and } W = \frac{v\gamma'(\gamma - 1)}{\gamma' - 1} \tag{21}$$

in the second case. In both cases, the fixed velocity *v,* the equalities will provide us with constant values of *u* that verify them. And this against the arbitrariness of the velocity *u* of the considered system! Therefore, by examining the thing from also the energy point of view, the de Broglie's relation remains incompatible, in whatever its form, with the principle of relativity and the usual definitions of *momentum*.

## 3 Conclusion

The various formulas we worked out constantly remind us the fundamental idea that in science the models with which you want to work are more important than theoretical formalizations! And in this case the model used, the wave associated with a particle, presents more than one problem. The particle, which is the unit, located in a point in space, is *distributed* in a wave characterized by its wavelength. It is the same de Broglie who postulates an oxymoron. In such a way de Broglie says in his Nobel Lecture:

> I thus arrived at the following overall concept which guided my studies: for both matter and radiations, light in particular, it is necessary to introduce the corpuscle concept and the wave concept at the same time. In other words the existence of corpuscles accompanied by waves has to be assumed in all cases. However, since corpuscles and waves cannot be independent because, according to Bohr's expression, they constitute two complementary forces of reality, it must be possible to establish a certain parallelism between the motion of corpuscle and the propagation of the associated wave[3].

The mingling of the two models is placed just on the basis, as we have seen, of all deductions thus reversing the role between physics and mathematics, the latter, not coming from definite elementary physical operations, can never have a *real* meaning but only a *formal* one. Thus, de Broglie's relation, widely regarded as essential both for the synthesis that operates between quantum theory and relativity and for its fundamental role in modern quantum mechanics, shows some uncertainties, as it was deduced, for its compatibility with the principle of relativity (which is also a fundamental postulate of Einstein relativity!) and, not the least, for its experimental verification; but on the other hand it is the same de Broglie who concludes his doctoral thesis in 1924 with these words:

> I have left the definitions of phase waves and the periodic phenomena for which such waves are a realization, as well as the notion of a photon, deliberately vague. The present theory is, therefore, to be considered rather tentative as Physics and not an established doctrine.[4]

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[3] de Broglie 1929, p 247.
[4] de Broglie [1924] 1925, pp 127–128.

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# The Emergence of Two Options from Einstein's First Paper on Quanta (1905)

**Antonino Drago**

**Abstract.** Two aspects of Albert Einstein's 1905 paper (*On an Heuristic point of view concerning the Production and Transformation of Light*) are examined: the kind of organisation of the theory and the kind of mathematics. It is shown that Albert Einstein (1879–1955) substantially made use of constructive mathematics, which is alternative to classical mathematics. Moreover, it is shown that Einstein organised the presentation according to the model of a problem–based theory, a model that is alternative to the traditional model of a deductive theory. This result makes it possible to illustrate in details the logical structure of Einstein's paper. In the history of theoretical physics, Einstein's theory was the first to manifest a consistent foundation on both the above–mentioned choices, which are the alternative to the Newtonian. In this profound sense this paper was very *revolutionary*.

Key words: Black body, Einstein, Kind of mathematics, Kind of organisation, Non–classical logic, Alternative foundations

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## 1 A Short Introduction: the Dichotomic Option of the Two Kinds of Mathematics

In the Introduction of the *Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt* (*On an Heuristic point of view concerning the Production and Transformation of Light*; Einstein 1905) Albert Einstein (1879–1955) stresses that in theoretical physics there exists a *profound formal distinction* between the use of *continuous spatial functions* (e.g. in electromagnetism), allowing a s*ubdivision into arbitrarily small parts,* and the use of the *finite* mathematics for representing discrete material points of a gas. This distinction is presented as an unavoidable dichotomy in our mathematical description of nature[1]. Subsequently, Einstein ponders on a typical theory relying on continuous mathematics, i.e. Maxwell electromagnetism: are there some electromagnetic phenomena, which cannot be explained by means of continuous mathematics? Are there some basic discrete physical notions (quanta)? The conclusion of the paper is in the affirmative[2]. Hence, Einstein suggests that in theoretical physics *there exists a dichotomic option of the kind of mathematics*.

Sixty years later, the mathematical dichotomy that Einstein – like the ancient Greeks – referred to, i.e. the dichotomy between the continuous and the discrete, was accurately formalised in mathematical terms: On the one hand, classical mathematics makes use – more or less freely – of actual infinity in both definitions and techniques (Kogbetlianz 1968, App. 2); on the other hand, constructive mathematics requires that any mathematical notion has to be defined by means of a finite algorithm

[1] The word "dichotomy" is Klein's (Klein 1980, p 167). Previously he qualified the Einstein's distinction as "a fundamental inhomogeneity in the foundations of physics" (Klein 1970, p 241). Some historians recall that according to Boltzmann a theoretical physicist has to be capable of reducing all mathematical notions to the discrete ones (Boltzmann 1874; Dugas 1959). However, this idea is not the same as Einstein's, who rather considered an actual dichotomy in the kind of mathematics, to be decided in agreement with the specific kind of phenomena to be dealt with.

[2] Dorling's (Dorling 1971, p 2) summarised the mathematical deductions in the sects 3–6 of Einstein's exposition by means of a diagram; the conclusions were correctly represented as analogies. However, sects. 5–6 were summarized . Notice that the word "deduction", in the title and in the text, means in fact "induction".

relying on the discrete (Bishop 1967, pp 1–10)[3]. Remarkably, the difference between the two kinds of mathematics is more subtle than the old difference between the continuous and the discrete, but it is evenly relevant for the foundations of a theory. Constructive mathematics includes continuous functions (for instance, analytical functions), Taylor and Fourier expansions, derivative and integral operations on uniformly continuous functions, differential equations and most of their solutions; thus, it covers almost the entire practice of the usual mathematics in theoretical physics. However, in general it does not obtain the single points as well as the global properties, since in it each approximation process does not necessarily achieve an accurate result.

Let us examine whether Einstein's paper (Einstein 1905) makes use of no more than constructive mathematics. Actually, in the sects. 1–2 and 4–6 he makes use of derivatives and integrals; since both operate on uniformly continuous functions, they have the counter–parts in constructive mathematics. However, in sect. 3 the technique aimed at obtaining a maximum on a set of functions is not constructive, since in constructive mathematics the exact equality between (two points and even more) two functions is undecidable. However, one may circumvent this difficulty by obtaining the same result through a substitutive argument of the thermodynamics of radiation, just as Pais (Pais 1979, p 873) did for simplicity's sake (notice that in this procedure Schwarz's equality can be considered an approximate equality).

## 2 The Alternative Organisation of Einstein's Paper

In Einstein's paper (Einstein 1905) the title qualifies his theory as "heuristic"; by this is meant first of all that the paper does not present principles–axioms. Moreover, let us consider Einstein's theoretical strategy. Whereas in his relativity paper he wanted to *reconcile* mechanics with electromagnetism by modifying mechanics according to the Lorenz group (Drago 2010), in his paper on quanta he wanted to reconcile electromagnetism with statistical mechanics (and also with thermodynamics) by changing the mathematics of the former theory into discrete mathematics. Hence, he had to organise the theory in order to

[3] For an elementary introduction, see De Martino and Drago 2002.

solve this new problem. Sadi Carnot's (1796–1832) theory (Pisano 2010) and several more theories are also organized in the same way each one starts from a problem and tries to solve it. I called this model of organisation the problem–based one (PO) (Drago 2007, 2012, 2013). An accurate examination of Einstein's presentation shows that his theory is organised according to the same model. In Einstein's paper the problem is located in the (middle of the) "Introduction"; he questions the universal validity of continuous electromagnetism; he guesses that this consolidated theory may lead to contradictions. After having stated the problem, each PO theory proceeds through a sequence of units of reasoning. In Einstein's paper, there are four units of reasoning.

In the sect. 1, he studies a case of electromagnetic interaction among radiation, molecules and electrons. By assuming the universal validity of electromagnetism, the classical equipartition theorem of statistical mechanics leads to an infinity; which is an absurdity in both experimental and theoretical terms. He concludes, implicitly, that it is not impossible that continuous electromagnetism fails. In fact, already Planck had produced theoretical arguments of electromagnetism, including a discrete notion – the energy quantum –, which have obtained the correct black–body distribution of energy. However, Einstein is dubious about Planck's theoretical method, since he wants to argue directly from experimental data.

However, in the sect. 2, Einstein proves that Planck's formula, without his theory, is able to accurately obtain a crucial result, the Avogadro number. Hence, a theoretical treatment of discrete electromagnetism is not impossible.

The sects. 3–4 constitute the third unit of reasoning. By thermodynamic arguments he obtains for the radiation the same formula $S=S(V)$ which holds true for a perfect gas; he explicitly claims an *analogy*; i.e., it cannot be excluded that radiation is composed by discrete objects (i.e. quanta).

The fourth unit of reasoning is recognised in the sect. 5–6; by following Boltzmann's approach to statistical mechanics, Einstein obtains an analogy between the microscopic distribution of gas' particles in space and that for quanta; i.e., the spatial distribution of quanta is not different from the distribution of the mutually independent particles of a gas.

In each PO theory the sequence of units of reasoning concludes a DNS, hence a mere hypothesis. Einstein too concludes a hypothesis, "[…] as thought […]" (Einstein 1905, p 143), that is equivalent to a DNS (= It is not true that… does not holds true). In the subsequent developments of a PO theory, this hypothesis is translated into the corresponding affirmative statements, from which all relevant theoretical previsions are drawn. Einstein as well, in the beginning of the sect. 7, translates the hypothesis of the sect. 6 in the affirmative statement: "[...] both incident and emitted light consist of energy quanta [...]" (Einstein 1905).

Then, in the sects. 7–9, he deduces formulas that successfully account for three new electromagnetic phenomena. Hence, the problem put by Einstein at the beginnings of the paper is solved; i.e., there exists a theoretical treatment of discrete electromagnetic phenomena. From a foundational viewpoint, Einstein's entire paper provides evidence for *an alternative kind of organisation to the deductive one, that we find in Newton.* After a few decades, Einstein stressed that physical theories are, with respect to – organisation, either *constructive theories* (e.g. statistical mechanics), or *principle theories* (e.g. thermodynamics and special relativity (Einstein 1934; Klein 1967)*;* of course, the theory of his paper on quanta is a principle theory. In sum, he pointed out *a dichotomic option of the kind of organization, which substantially overlaps with the dichotomy AO/PO.* However, like the authors of the other PO theories, he was unable to qualify this alternative organisation accurately. However, as matter of fact, they all unwarily argued by means of doubly negated statements (DNSs) whose corresponding affirmative statements do not hold true owing to the lack of evidence for the latter. In logical terms, in these cases the double negation law fails, hence, a DNS belongs to non–classical logic (Troelstra and van Dalen 1988, 56ff.). Einstein's 1905 paper makes a large use of DNSs, e.g. "[...] quanta move without dividing [...]"; "equivalent" (= "It is not true that… is not equal" ≠ it is equal). In the 5 pages of the sects. 1–6 of Einstein's paper I recognised 55 DNSs. A more important verification of the theoretical relevance of the DNSs is the author's use of them for arguments concluding no more than DNSs. E.g., in Sadi Carnot's thermodynamics, the author proves through DNSs his celebrated indirect proof (Carnot S 1978, pp 20–21); whose conclusion is a DNS: the efficiency of irreversible machines is lesser than the efficiency of reversible ones.

In Einstein's paper, many arguments seem to be the usual mathematical derivations. Maybe this was Einstein's opinion too (Let us recall that the more important non–classical, intuitionist, logic, was formally founded two decades later). However, before the final conclusion, his language manifests a jump from the mathematical development to an analogy, since he wrote "From this we further conclude that [...]" (Einstein 1905, p 1431) where "further" here means "in addition". Indeed, the conclusion of his reasoning is nothing more than an analogy; which is equivalent to a DNS, as the conclusion of every PO theory is. Notice that Dorling (Dorling 1971, pp 3–6) suggested how to substitute for the final analogy some probability arguments, all constituting indirect proofs, as S. Carnot's proof is[4].

## 3 Conclusion. The Revolutionary Role played by Einstein's Paper in the History of Theoretical Physics

In the above, it was shown that Einstein's paper *substantially manifested both alternatives to Newton's foundational choices*. Previous theories relying on the same alternative choices – Lazare Carnot's mechanics, Sadi Carnot's thermodynamics (Carnot L 1786; Carnot S 1978) and special relativity – were all unsatisfactory owing to, respectively, a confused use of non–classical logic, an essential use of a subsequently discarded hypothesis of caloric (Drago and Pisano 2005), a deviation from the PO model after the first pages (Di Matteo and Drago 2006). Hence, in the history of physics, Einstein's paper introducing quanta presented the first theory consistently developed according to both the alternatives to Newton's choices. In this profound sense, concerning the foundations of theoretical physics, his paper constituted the most *revolutionary* paper among Einstein's ones of the first years of the last Century. This fact constitutes a more stringent argument than Kuhn's (Kuhn 1978) for attributing to Einstein the priority in the historical process which led to the discovery of quanta, the crucial notion of quantum mechanics.

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# Planck's "Long and Multiply Twisted [and Inconclusive] Path" Towards a Black Body Theory

**Antonino Drago**

**Abstract.** Karl Ernst Ludwig Max Planck (1858–1947) suggested the quanta through a long series of calculations aimed at solving the problem of black–body radiation. These calculations are easily divided into six groups. It is shown that each group is disconnected from any other group. Planck's successful results are justified as either lucky calculations or retrospective calculations from the Wien's experimental law. Several scholars pointed out strong theoretical reasons for considering them insufficient to provide a correct notion of quanta of energy. By applying an operative definition of incommensurability, it is proved that they are insufficient because Planck ignored the mutual incommensurability in the relationship between the classical theories and the new theory.

Key words: Planck, Black Body Theory, Quanta

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## 1 The Six Periods of Planck's Calculations

In order to study the case of black body radiation, Max Planck (1858–1947) produced long and complex calculations all aimed at obtaining a radiation distribution of the black body, in agreement with Wien's law. Darrigol called them the "intricacies of Planck's thought" (Darrigol 2001, p 219). These calculations are easily severed into six groups, as illustrated by the following table[1].

**Table 1** The periods of Planck's calculations

| Period | Approach | Results | Notes |
|---|---|---|---|
| 1897–1898 Pre–statistics | Hp: Maxwell equations Plane waves re–emitted by resonators, Tactics: search of a *S=S(U)* | Nothing valid nor approximating to Wien's law | Planck ignores why in the dipole the re–emission does not give irreversibility |
| 1898–1900 Natural radiation | Hp: Maxwell eq.s, Natural radiation, Definition of a state equation. *S=S(U),* He imposes $\Delta S=0$ (2° principle of Thermodynamics) | Wien's law First evaluations of the universal constants *K* and *h*, ($d^2S/dU^2 = \alpha/U$) | Analogy with molecular chaos, A priori definition of the function *S=S(U)* |
| 1900 Interpolation | Hp: Additive *S* on resonators, Heuristics on previous formula: from $d^2S/dU^2 = \alpha/U$ to $d^2S/dU^2 = \alpha/U(\beta+U)$ | New law of radiation distribution [of quantised energy] | New experimental law, Planck's heuristics [a posteriori?] |
| 1900 | Hp: From the | Function | Novelties with |

[1] Detailed commentaries of these calculations are the following: Rosenfeld 1936, pp 155–169; Jammer 1966, pp 10–46; Klein 1970 pp 219–238; Kuhn 1978, Chaps III–V, X; Mehra and Rechenberg 1982, pp 33–45; Needell 1980; Darrigol 1988, pp 41–57; Badino 2009. For a long commentary, also on the historians of this case–study see Gearhart 2002.

| | | | |
|---|---|---|---|
| Oct. and Dec. Probability | concepts: cells, probability, complexions and quantized energy of oscillators, *h*, he obtained again *S=S(U)* and the new distribution results | *S=S(U)* $\varepsilon=h\nu$, New law of radiation distribution, Evaluations of the universal constants *N, K, e* ! | respect to Boltzmann's statistical mechanics, Quantised resonators in spite of continuous radiation |
| 1906 The *Lessons* | Previous writings are re–organised, Successful comparison of the previous two methods | The two methods agree, Both obtain the new Wien's law, $\varepsilon=h\nu$, Universal constants | See notes on the previous two periods |
| 1911 Second theory | Quantistic emission and continuous absorbtion $T_{em}=T_{td}$ | See the above | Inconsistent comparison of classical aspects and quantistic aspects |

## 2 Merits and Defects of Planck's Calculations

These calculations deserve great merit since *they obtained Wien's law five times and even the absolute constants.* However, the temporal sequence of the six periods is never in logical sequence. The calculations of the first period lack the hypothesis of natural radiation; from which, however, are derived those of the second period. The latter ones aim at reproducing the formula of Wien's theoretical and experimental law. However, between the second and the third periods, new experimental data led scholars to correct this law. Planck was therefore obliged to change, in the third period, the previous state function, *S=S(U)* (where *S* is entropy and *U* the energy of the system), from which he had successfully obtained Wien's previous formula. He heuristically interpolated the previous *S(U)*; hence, no deductive path from the two periods exists. In the fourth period, Planck defined anew the notion of entropy by starting from probability; hence, these new calculations for obtaining *S=S(U)* are apart from the previous ones. In the fifth period (*Vorlesungen*) Planck re–arranged previous calculations of the third and fourth periods and connected them. In the next "second theory" the calculations aimed at defining an electromagnetic temperature to be equated to the thermodynamic one; this approach is quite new. In sum, among the groups of calculations *there is no logical deduction* (apart from, of course, between the calculations of the fifth period from those of the two previous periods). Let us ask: *in each period, are the calculations well justified and consistent*? In the following I summarise the numerous defective points of Planck's calculations[2]:

**Table 2** The defective points and faults of Planck's calculations

| Planck's calculations | Criticisms |
|---|---|
| 1897 (1st communication): Introduction of irreversibility in electromagnetism | The thermodynamics of irreversible processes will born 30 years later. However, he imposes $dS$=0 |
| 1897 (1st communication) Hp.: Irreversibility generated by the resonator's re–emission | This process is reversible. Planck accepts this Boltzmann's criticism, but without declaring his change of address |
| 1898 (2nd period): Hypothesis of natural radiation. Is it incompatible with Maxwell equations? | No Planck's answer. In fact it is a hypothesis on the relationship between the theory and the physical reality |
| 1898–1900 (2nd period): Equivalence of $n$ resonators, each with energy $u$, and 1 resonator with the sum of the single energies, $U$ | Error (Lummer e Wien 1900), "a pretty sophism" (Darrigol 1988) |
| 1898–1900 (2nd period): Uniqueness of his $S=S(U)$. | Afterwards, he retreats this thesis. His linear model is insufficient to select the function $S$ and also to represent the variations of the distribution to that of max $S$ (Ehrenfest 1905 and 1909) |
| 1900 (3rd period) He interpolates two functions | "a lucky guess" (Planck) |
| 1900 (4th period): Calculation of $S= K \log P$ through the complexions | Not a unique definition of probability. It was unexplained (Lorenz 1903, Jeans 1905). Without the limit $h\nu \rightarrow 0$ (Lorenz |

[2] The criticisms were presented in part by (Jammer 1966), all by (Klein 1970), and then in detail by (Kuhn 1978).

| | |
|---|---|
| | 1903). Without the equipartition theorem. (Ehrenfest 1905 and 1909). Inconsistent comparison of classical resonators with quantized radiation The calculation is bounded to the range $hv<<KT$ (Einstein 1906) |
| 1913 (6th period) Comparison between the classical thermodynamic temperature and the quantistic electromagnetic temperature | Inconsistent comparison of two completely different theoretical approaches |

In conclusion, *Planck's calculations in each group are either off target (the first and the second ones) or inconsistent (the second ones) or inadequate (the remaining ones).* Moreover, *some logical steps are still mysterious: How did he obtain the interpolation of S(U)? How for the first time did he obtain the value of h? Why did he fix the cell's dimensions?*

## 3 Conclusion

The above shows that he started *a revolution in the fundamental concepts of theoretical physics (continuum, entropy, energy) not only without a clear strategy to solve the problem at issue, but also without valid calculations* (apart, perhaps, from retro–deductions)[3]. Indeed, Planck did not have a clear idea of the theoretical import of his new hypothesis of quanta[4]. He did not see precisely what (quantum) there was beyond the door he was opening (radiation distribution law, universal constants). At

[3] In the title of Chapter VI Kuhn uses the words "[…] demolition of Planck's theory […]" (Kuhn 1978, Chapter VI). The Universities often use to teach the black body theory through Planck's calculations of probabilistic *S*. They are correctly presented only when they are declared to be no more than merely theoretical approximations.

[4] See (Rosenfeld 1936, p 169; Klein 1970, pp 228ff; Kuhn 1978, Chaps V, X; Darrigol 1988, pp 20, pp 3–66). One may suppose that – for other physicists its most important theoretical results were the accurate evaluations – of absolute constants. However, several years passed before textbooks included the new figures (Klein 1966, p 30).

present, we know that Planck's theory gained a glimpse of quantum mechanics, which in this case involve many more problems than those he saw.[5] Historians were reluctant to recognize problems in Planck's writings.

**Table 3** The problems recognised by historians in Planck's writings

| Problem | Declared problems | Recognised, but neglected problems |
|---|---|---|
| Luck | Rosenfeld (1936), Norton (2005) | |
| Priority | Kuhn (1978) | |
| Insufficient knowledge of previous literature | Klein (1960) | |
| No firm basis | Klein (1980) | |
| Inconsistency | Jammer (1966) | Klein (1970) Kuhn (1978)[6] |
| Incommensurability | | Kuhn (1984) |

Moreover, after a century no one obtained new mathematical calculations deductively connecting both classical theories (electromagnetism and thermodynamics) to the quantistic theory in the case of the black body

[5] As an instance, let us take the indeterminacy relations. Since Planck defined the energy quantum *hv* with absolute accuracy, he had to consider the result of a measurement of the conjugate variable, time, as an infinite interval. Fortunately the study of the black body dealt with this time interval, because this study relies on thermodynamics (which is the only physical theory, apart from geometrical optics, in which the time of a transformation is a priori infinite; see e.g. the definition of reversibility), not Newtonian mechanics, which at that time was the dominating theory. Maybe for this reason the problem of black body, being of a thermodynamic nature, was the first to lead to quantistic results.

[6] In order to justify these defective points, Darrigol (2001, p 237) introduced the notion of "soft coherence" as opposed to "hard coherence" (which is the usual consistency). My opinion is that the first notion qualifies as acceptable a research method only when it is first presented; but later this method has to be accepted only if it is "hard coherent", otherwise it has to be rejected.

radiation[7]. This failure is enough to enable us to declare – as Kuhn did intuitively (1984, p. 245) – incommensurable the mutual relationships of the theories of this case–study. Elsewhere (Drago 1987) I suggested an operative definition of incommensurability: two theories are incommensurable when they differ in the choice of the kind of mathematics (either classical or constructive) and/or the choice of the kind of organisation (either the deductive one or the problem–based one). In the first three groups of calculations Planck takes the respective first choices (infinitesimal $dS=0$, deductions form an a priori $S$); they formally compared classical aspects with quantistic aspects, where the mathematics is discrete; hence there is an incommensurability. The groups of calculations from the fourth ones on, changed the kind of mathematics (they quantised both cells and energy); however, they preserved a partial description of a basic object, the oscillator; again the two different kinds of mathematics generate an incommensurability; that means that there is no common mathematical language, hence no possible deduction in mathematical terms; exactly what the experience of a century shows.

I conclude that *Planck's writings* are not useful *for illustrating the deep changes that occurred at his time in the foundations of theoretical physics*. Planck hoped to have an Arianna thread (to introduce entropy into electromagnetism); but, before Nernst's third law, it was too weak for suggesting how to introduce discrete mathematics, which Planck's calculations actually introduced either in a weak form (through natural radiation and statistical mechanics), or abruptly (the introduction of $h$ without explanations).

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[7] On that see Darrigol 2009 who tried to find out a consistent didactics of this case study.

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# From Science to Philosophy: Alfred North Whithead and the Notion of Process

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**Abstract.** Ilya Prigogine (1913–2003) discovered that importation and dissipation of energy into complex systems could reverse the maximization of entropy rule imposed by the second law of thermodynamics. Beginning from a sketch of what a complex system consists of and some epistemological consequences, I will show which instances of *process* approach are able to give some preliminary ontological basis for a more adequate understanding of nature with its own indeterminacy, surfaced as empirical evidence inner non–linear thermodynamics. The idea is to connect these issues for reinterpreting the verification principle in experimental method, avoiding Popper's criticism to it and in agreement with falsification procedure.

Key words: Asymmetries, Complexity, *Modus ponendo ponens*, Non–linear thermodynamics, Prigogine, Processes, Whitehead

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## 1 An Epistemology for Complex Systems

In relation with the changing paradigm, in the second half of the last century, due to the discovery of complex dissipative systems in physics (discovered by Edward Norton Lorenz (1917–2008) in 1963), the epistemological issue as posed by Ilya Prigogine (1913–2003) is:

> The traditional expression of natural physical laws opposed the fundamental a–temporal laws against phenomenological descriptions involving the time's arrow. Considering the 'chaos' leads also to a new coherence, to a science that does not treat just laws but also events, which is not condemned to deny the emerging of novelty, that would imply the refusing of its own creating activity[1].

Real physical systems are complex; complex but simple, in the sense they are at least constituted by more than two ($n > 2$) bodies. What makes them complex? That a) their constituents are in mutual interaction; that b) their dynamic behavior is mathematically described by non–linear differential equations; that c) they show stationary structures out of equilibrium. For all of that they are intrinsically evolutionary and non–reversible phenomena. Simply, complex systems show a new kind of coherence: their own structure rises out from the matter in out of equilibrium conditions. Those structures are 1) stable *even if* the material system is in continuum interaction with – exchanges energy in/out with – the external environment, i. e. they are dissipative; and they are 2) unified large–scale correlations that characterize the system as a whole: getting intrinsic dimensions (Prigogine 2008, pp 15–16). Thus, complex systems show a dynamic behavior characterized by i) *high sensibility* to a weak perturbations of start–point conditions (defined by canonical variables: position $q$ and momentum $q$); ii) the *breaking of symmetry*: perturbations break the symmetry among evolutionary solutions; and iii) *irreversible development* (real evolution): the breaking of symmetry make the process irreversible (Prigogine 2008, p 18). From an epistemological standpoint, we can already claim that the study of this kind of real systems is opposed both to materialism and mechanism own foundation of natural physical laws (a–temporal laws) respectively characterized, in synthesis, by two "directions" (Basti 2002, p 143): *a*) the *synchronic* direction, that reduces the behavior of complex systems, constituted by an huge number of

[1] Prigogine 2008, p x. Author's quotation marks.

elements, to laws regulating the behavior belonging to their elementary constituents (atomism); *b*) the *diachronic* one, that reduces the final state of a physical process to its start–point state conditions (mechanism: initial conditions + dynamic evolutionary laws). These univocal reductions are both proper of stable systems only (Prigogine 2008, p 28).

## 1.1 Non–Deterministic Laws

The path that describes the energetic fluctuation of the system through the time, attains energetic conditions by which the unique trajectory ceases to exist. At these bifurcation points there are no more defined trajectories and *prediction is inherently probabilistic*[2], and not just statistical. It means that from the knowledge of initial conditions, it is not possible any univocal prediction of any final state, and *vice versa*; whereas, among bifurcation points the prediction is deterministic (Prigogine 2008, pp 18–23). It entails that complex systems have a *constructive role*, not hence reducible to phenomena going linearly toward disorder. Indeed, although the global thermodynamics direction of the universe (isolated system) goes toward the increasing of entropy (toward disorder), *locally the order emerges from chaos*, from minimal grades of complexity to higher specialized structures: locally, the second law of thermodynamics seems to be broken or, at least, inverted. Locally order emerges *from chaos* at least because, for the *third law of thermodynamics*, it is impossible to achieve *the* maximum of entropy, and hence it is really *impossible* to achieve dynamically, for a physical system, a state in which there are no interactions, i. e. no fluctuation of energy, at quantum level. It entails the most basic quantum level, the quantum field, is itself out of equilibrium and hence unstable and, therefore, chaotic.

There is a mathematical difference between linearly stable and non–linearly stable system. The former is led and described by linear differential dynamic equations: linearity means that the uncertainty (ε) –

[2] "The only one kind of equations whom we can treat mathematically is linear ones […]. The necessity for linear equations corresponds to one of the most important properties of our universe; the concept of causality would not be possible, or would be really different, in a universe governed by non–linear equations, because the whole effect of two agent causes together would not be the sum of the effects produced by them acting separately, hence would not be possible the analysis" (Bridgman [1927] 1965, p 171).

depending on the measurement of the initial conditions (*p*; *q*) – among trajectories, by which the evolution is represented on the *space of phases*, is invariant: trajectories keep the distance ε (Basti 2002, p 144). Instead, the latter is led and described by non–linear differential equation: non–linearity means (*Ibidem*) 1) that the *uncertainty* (ε) among trajectories, is *variant* and 2) that the *amplitude* of ε exponentially *increases* along the whole evolution, diverging among themselves: a small perturbation at initial conditions produces a huge variation at final state and those systems get a strange behavior named *chaotic*. Chaotic but not stochastic: in fact, the use of differential equations means a correlation between two successive discrete states, and, further, their non–linearity is *not depending on variables' number* involved. A first proof of this is represented by the *Three–Body Theorem* (1887, by Henri Poincaré (1854–1912)) which demonstrates that a dynamic system of only three bodies (mathematically represented by non–linear differential equations) is not predictable for long periods against the *Ergodic Hypothesis* for which randomness is connected with the variables number (1872, by Ludwig Eduard Boltzmann (1844–1906)). Hence, non–linearity means an intrinsic instability to dynamic systems, defined by a physical criteria (see Prigogine 2008, p 20, pp 55–56) against its connection with the formal representation (Prigogine 1981, pp 206–212). Thus, there is a *lack of proportion* between cause and effect or, better, between perturbation measurement at the initial state and its variation at the last state of physical process (end/final state)[3].

## 2 An Ontology for Complex Systems

According with Prigogine (Prigogine 1981, p 279), some elements of Alfred North Whitehead's (1861–1947) cosmology could provide logical and ontological principles adequate for a foundation of complexity in Physics. The task of his cosmology, as posed by himself, is:

[3] For a better understanding of *deterministic chaos* Cellucci provides a mathematical example (Cellucci 2002, p 335), and Ruelle gives a physical explanation (Ruelle [1991] 2013). To sum, there is a total loss of information *in* the system, and not only *about* the system.

> Thus the problems for Nature is the production of societies [= many entities] which are 'structured' with a high 'complexity', and which are at the same time 'unspecialized'[4].

Whitehead's cosmology and its fundamental notion of *process* are concerned with one basic problem (Whitehead 1929–1960, III, 1, p 127): to provide a correct comprehension of the emerging of *order* – namely, structures and, hence, laws – in the universe. Obviously, the correlative of order is *disorder*, and these notions are entangled for the gradual constitution of the nature of each real singular thing. The process sustains the gradual transition to new types of order from disorder, supervening as present natural laws. *Gradual* because there is always disorder, such as laws are not perfectly obeyed (Whitehead 1929–1960, III, 1, p 140): there is *not just one ideal* (or linear) order which all actual entities should *completely* attain and/or fail to attain (Whitehead 1929–1960, III, 1, p 128) at the same time. Whitehead's ontology sustains notions of *order* and law as not based on classic logic (extensional), as it was for moderns. Indeed, a society of many entities is more than a set: it involves *more than a merely mathematical* (analytic) *conception of order* because any societies – any real physical system of many ($n > 2$) entities – is not in isolation (Whitehead 1929–1960, III, 1, pp 137–138)[5]. A first consequence of Whitehead's doctrine as outlined above is the dynamic distinction between, respectively, *structural stability* and *instability*, as constitutive of real opened system[6]: a) stability depends on *actual* environmental *conditions*, in opposition with the dependence on initial conditions; b) instability depends on *non–equilibrium* dynamics and to *non–linearity* in describing equation. In an adaptive logical view, a complex society – of elements constituent a more complex thing, a whole – is at the same time "specialized" (stable), namely structured with a grade of complexity and "unspecialized", with respect to its own structural pattern (Whitehead 1929–1960, III, 4, pp 153–154). The defining characteristic of such a society will not include any particular determination of structural pattern

[4] Whitehead, 1929–1960, III, 6, p 154. Author's quotation marks.

[5] "It must be considered with its background of a wider environment of actual entities. Thus the given contributions of the environment must at least be permissive of the self–sustenance of the society" (Whitehead 1929–1960, III, 1, p 138).

[6] "A society may be more or less 'stabilized' in reference to certain sorts of changes in that environment". (Whitehead, 1929–1960, III, 6, p 153). Author's quotation marks.

(it does not depends on temporal/historical evolution), because that special pattern is adapted to the circumstances of the moment, or better, it depends on *actual conditions* (Whitehead 1929–1960, III, 4, pp 153–154) – provided by the dynamic openness to an energetic and informational exchange (in/out) with the environment – by which it is *large–scale ordered*, in the sense that many constituents are interconnected and, hence, ordered among themselves (Whitehead 1929–1960, III, 2, p 136), in order to the fundamental measure of order provided by the whole new entity. A real physical theory of evolutionary systems needs to coherently explain a hierarchy of structures by 1) an actual stability, and 2) a real and effective evolutionary process (Whitehead 1929–1960, III, 2, p 139). Therefore, has to provide *a*) an *horizontal evolution*, to justify the becoming of nature: gradual transition to new types of order; and *b*) a *vertical progress*, based on the foundation of an increasing ordering of complexity, through a specialization of formal characteristics: physical relations, geometrical relations of measurement are derivative from a series of societies of increasing width of complexity (Whitehead 1929–1960, III, 2, pp 140–141). Therefore, we need a process able to put, keep and satisfy the mutual correlation between stability and instability (dynamics), or between determination and indetermination (static); and this, hence, requires and supposes that the process of becoming of nature is not *a priori* determined, because the process retains indetermination is, and only if it is *blind* (Whitehead 1929–1960, III, 2, p 325) – not presupposing any formal determination (any *a priori*), as well as if controlled/governed by an intellectual and intentional act[7]. Going deeper into Whitehead's cosmology, there are two entangled principles of each process: 1) the *concrescence*, by which many things acquire an individual unity in a determinate relegation of each item of the *many* to its subordination in the constitution of the novel *one* (Whitehead 1929–1960, III, 2, p 321) and 2) the *transition*, that is a process proceedings from phase to phase, each phase being the real basis from which its successor proceeds toward the completion of the singular novel thing. The former is the local process, whereas the latter is the global one. So, those processes are mutually related, namely each actual entity although complete so far as concerns its local process, is yet incomplete by reason of its inclusion of the global process (Whitehead 1929–1960, III, 5, pp 326–328). Namely, entities ere

[7] "'Blind' in the sense that no intellectual operations are involved" (Whitehead 1929–1960, III, 2, p 345). Author's quotation marks.

constituted by their real genetic phases (cardinal series), but as an ordered series of *discrete states*. Order provides by the former process is given by the *ends actually* attained, that is just the last state of the series, in order to which the whole series is ordered. In this, Whitehead recognize the physical evidence that the future must be *in some sense* actual, although the completed actualities of that future are undetermined (sub–specified).

About the formal evolution of a complex system, this does not determine univocally one final state, whereas could determine a plurality of possible future (final) states, each one product with a certain frequency. This shows two issue: 1) the *equivocal* nature of the cause–effect relation and 2) that the process *itself* determines, with respect to the successor effectively product, *the functional relation* $y = f(x)$ that represents the process in a necessitate and formal–univocal way. Summing up (Basti 2002, pp 447–448), a plurality of causes P will produces a plurality of effects Q, instead of only one $q$. The physical process, in order to the final state achieved (effect) specializes/determines both pluralities P and Q, and their mutual relations. The process makes the generic *non–ordered* collections P and Q, two *ordered* sets with their mutual relations (mathematically formalized as functions). The *final state* effectively prodoucted has got an *ordering effect on* the two *collections* P, Q, obtaining a biconditional/symmetrical relation (↔), *as it is required by a necessary and biunivocal deterministic relation*.

## 3 Conclusion: Demonstrative Procedure in Probabilistic Processes

Accordingly with uncertainty of prediction, the hypothetical form ‘if $p$ then $q$’ ($p \rightarrow q$) – where $p$ and $q$ are descriptive statements, respectively belonging to initial and to final states – has to be reanalyzed: *a*) it is impossible to know *a priori* which $q$ is necessarily implied by $p$, and *vice versa*; *b*) the *ordering* of P and Q depends *a posteriori* on the *being of final state* (Basti 2002, pp 447–448). So, the two forms of hypothetical reasoning, *modus ponendo ponens* (MPP: ($p \rightarrow q$) ∧ $p \rightarrow q$) and *modus tollendo tollens* (MTT: ($p \rightarrow q$) ∧ $\neg q \rightarrow \neg p$), are now *both* formally valid, *but differently considered* from the neo–positivist interpretation.

In agreement with the Popper’s criticism to the neo–positivist approach to the validation of hypothesis, the *verification principle* is in reality schematized by a non–validating form of argument, a logical fallacy (logically always false) called *affirming the consequent* (($p \rightarrow q$) ∧ $q \rightarrow p$), namely, there is inconsistency since *p* is never asserted as the only sufficient condition for *q*, other facts could account for *q* while the *p* is false. Within the non–linear physical systems and indetermination of laws, MPP reenters in the epistemology of empirical method avoiding Popper's restriction to MTT (as the only instanced valid form in it). In fact the new interpretation consists of considering (in MPP) *p* as representing the *final state* of the process (the effect), instead of being the initial conditions; and *q* representing the *initial state* of natural process (the cause), instead of being the effect (Basti 2002, p 448).

Concluding, what for logic is *a priori* in the formal demonstration procedure, i.e. the antecedent of premises, must derives *a posteriori* from the being really effective (= ended and determined) of contingent complex physical process (= inherently probabilistic), i.e. the final state of it (Basti 2002, p 450).

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# 1772–1813. On Early Scientific Activity of the Astronomical Observatory at University of Coimbra

**Fernando Bandeira Figueiredo**

**Abstract.** The establishment of scientific education at the University of Coimbra was one of the most important accomplishments of the Reform of the University in 1772. One of the best examples is the creation of the Faculty Mathematics and of the Astronomical Observatory (OAUC). The foundation of the OAUC – the first Portuguese university–based astronomical observatory, although with attributes typical of a national observatory – was fundamental in the institutionalization of astronomical science in Portugal. José Monteiro da Rocha (1734–1819) was the central personality beyond the conception, planning and construction of OAUC, as well as in its instrument's provision. He was also behind the applied mathematical and astronomical methods that allowed the OAUC to establish and publish its most important and significant scientific production: the *Astronomical Ephemeris* (1803). In this paper, we will review Monteiro da Rocha's contributions for the foundation of the OAUC and its scientific astronomical activity.

Key words: 18th century, University of Coimbra, Astronomy, Observatory, Astronomical Ephemeris

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# 1 A Short Introduction

Between 1770 and 1772 king José I (1714–1777), and his Prime Minister, Marquis of Pombal (1699–1782), started a major Reform at the University of Coimbra (created by king Dinis in 1290). This Reform (known by *Reforma Pombalina*) had the major objective of synchronizing Portugal with the ideas of the enlightened Europe. The University, as an instrument of the State, would be an irreplaceable and forceful tool in the development of a modern society, 'enlightened' by science and technological progress. With that purpose, faculties were erected for Mathematics, Natural Philosophy and Medicine, and their scientific courses organized under a modern syllabus and curricula. It can be said that this Reform at the university's studies begins the process of institutionalization of science in Portugal, namely of Mathematics and Astronomy (which, for the latter, concurred with the inauguration of the OAUC in 1799). One of the main actors, that stands out in this whole process of Pombal's Reform of the University, is José Monteiro da Rocha (1734–1819). He was one of the leading designers of the new curricula for mathematics and astronomy and he played a central role in all ensuing teaching, scientific and administrative activities of the University's life, both as professor and Director of the OAUC.

## 1.1 José Monteiro da Rocha

José Monteiro da Rocha was born in a small town in the north of Portugal on the 25th of June 1734. Very little is known about the first years of his life. It is known that he joined the Jesuits in his youth (1752) and left Portugal to go to Brazil where he studied at the Jesuit school of Salvador da Bahia (1752–1759). Following the expulsion of the Jesuits from Portugal in 1759, Monteiro da Rocha left the Society of Jesus and later returned to Portugal (1766). In 1771, he was called by Marquis of Pombal to participate in the educational Reform of the University of Coimbra. Henceforth he will be the lecturer in charge of the courses of Physics and Applied Mathematics (1772–1783) and Astronomy (1783–1804).

Monteiro da Rocha was also nominated to other important academic positions. In 1780 he was elected full member of the Royal Academy of Sciences of Lisbon (created in 1779), and in 1795 he was appointed Dean and Permanent Director of the Faculty and Director of the Royal Astronomical Observatory of Coimbra University. He was also Vice–

Principal of the University from 1786 to 1804. In 1800 Monteiro da Rocha became member of the royal council of Prince Regent João VI (1767–1826) and in 1804 became tutor of Prince Pedro (1798–1834) (future Emperor of Brazil and King of Portugal) and moved to Lisbon where he will die on 11 December 1819.

Monteiro da Rocha was a key figure in 18th century Portuguese science. His scientific work covered quite separate mathematical and astronomical domains. The astronomical work of Monteiro da Rocha spans from theoretical to practical astronomy, the most significant elements being: a work on the determination of comet's orbits, several papers on calculation of eclipses, on longitudes; astronomical tables of the sun, moon and planets and charts of Jupiter satellites, on the use of the rhomboidal reticle, and on the use and calibration of the transit instrument. His work on the determination of comet's orbits (Rocha 1799) is frequently cited by Portuguese historians of science as one of his greatest scientific contributions (Leite 1915; Carvalho 1985). This is justified for two main reasons. First, because in his paper Monteiro da Rocha presents a simple method for calculating the parabolic orbit of a comet from 3 observations; the second reason, and perhaps the most relevant, is that his work dates from 1780–1782, before Wilhelm Olbers (1758–1840) publication (1797), but unfortunately it was eventually published in Portuguese only in 1799; the two methods are very similar (Figueiredo and Fernandes 2006)[1].

[1] The problem of determination of comets orbits was one of the most difficult from the time of Newton's Principia (1687) and one which received enormous contribution by several astronomers and mathematicians during all 18th century, such as Edmond Halley (1656–1742), Leonhard Euler (1707–1783), Marie–Jean–Antoine–Nicolas de Caritat marquis de Condorcet (1743–1794), Ruđer Josip Bošković (1711–1787), Erik Prosperin (1739–1803), Jérôme Lalande (1732–1807), Joseph–LouisLagrange (1736–1813), Pierre–Simon, marquis de Laplace (1749–1827) and others. In 1772 the Berlin Academy of Sciences proposed a prize to be awarded in 1774 to whom discovered a simple method to determine the parabolic orbit of a comet using only 3 observations. This award was only granted in 1778 to Condorcet and Tempelhoff (1738–1808). Nevertheless, it was Olbers who got the historical credit as the inventor of a simple and easily applicable method that was published in 1797 under the sponsorship of Baron von Zach (1754–1832).

## 2 The Astronomical Scientific Activity at the OAUC

The idea to build an astronomical observatory was settled down in the Statutes of the Reformed University of Coimbra. The mission and the astronomical practice assigned to it in the *Statutes* hold a particular dichotomy. On the one hand as a university observatory, devoted particularly to the practical teaching and the scientific research of their teachers, was required *to rectify the fundamental elements of the astronomical science*; and, secondly, as a national observatory that must be involved on the preparation of the astronomical ephemeris f*or the use of the Portuguese Navigation*. The creation of OAUC was fundamental for the institutionalization of astronomical science in Portugal in the second half of the eighteenth century, a period in which astronomy, supported by major theoretical advances of celestial mechanics and of applied mathematics, tries to finally solve the major issues that it had been facing since Newton's time. These issues, related to the problems of navigation, geodesy and cartography, determination of planets and comets' orbits, measurements of time, and which were part of the work plan of any observatory of that time, are also the basis for the creation and planning of the OAUC. Initially, the building was planned for the site where the castle of the city of Coimbra was erected – not far from the University – (Freire 1872). However, due to financial constraints, its construction halted after 3 years, and it was eventually built within the walls of the University during the 1790s. The building had a rectangular configuration (41m length), and consisted on three contiguous bodies, where the central one (with 24m of height) was three times taller than the others on each side.

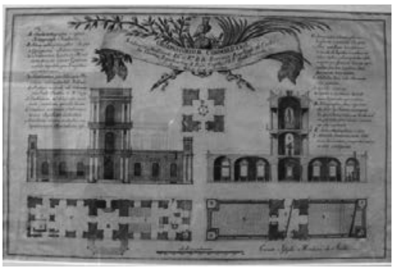

**Fig. 1** Plant (1799) of the OAUC[2]

[2] The OAUC's library [OAUC G-006].

After its inauguration in 1799 the scientific activity of OAUC, under the responsibility of Monteiro da Rocha, was focused on the calculation and publication of the *Ephemerides Astronomicas do Observatório Astronómico da Universidade de Coimbra* (Astronomical Ephemeris) (EAOAUC). The 7th paragraph of the chart in law (04/12/1799), that regulates the OAUC mission, establishes unambiguously the calculus of the astronomical ephemeris as its main purpose:

> The Astronomical Ephemeris should be calculated for the Meridian of the Observatory, for its own use (a common practice of the most famous Observatories of Europe at this time), and for the use of the Portuguese mariners; the Ephemeris should not be reduced or copied from the English Nautical Almanac, or from any other, but calculated immediately from the Astronomical Tables.[3]

## 2.1 The Astronomical Ephemeris of the OAUC

The first volume of the EAOAUC was published in 1803 (by the University's press), with the astronomical data for the year 1804 and providing all the conventional astronomical data (12 pages for each month with the position of Sun, Moon, planets and lunar distances). Since the 1st volume the EAOAUC adopted some particularities: they were calculated in reference to the mean sun and not to the true sun (as the *Connaissance des Temps* or the *Nautical Almanac*). They used the 360° measure and not the widely used sign unit; they provide the "lunar distances" not only for the Sun and stars but also for Mars, Jupiter and Saturn. Unlike the foreign Ephemeris where the positions of the Moon were calculated for both the noon and midnight directly from the astronomical tables, at the EAOAUC only the noon position was directly calculated from the tables, being the position for midnight calculated by a particular interpolation method proposed by Monteiro da Rocha (Rocha 1808, pp 121–180). This method that made use of finite differences up to 8th order, also served to calculate the lunar distances to other instants (in the EAOAUC the lunar distances were tabulated every 12 hours).

[3] Archive: 1803. *Ephemerides Astronomicas do Real Observatório da Universidade de Coimbra*, Imprensa da Universidade Coimbra, p.v.

Similarly, to the Connaissance des Temps, several scientific articles were written by Monteiro da Rocha and published enclosed in each volume. Some of these were translated and published in France (Rocha 1808) by Manuel Pedro de Melo (1765–1833), a former student of Monteiro da Rocha, who worked with Jean Baptiste Joseph Delambre (1749–1822) at the Observatory of Paris. In fact, due this connection between Pedro de Melo and Delambre the EAOAUC deserved very favorable book reviews in Connaissance des Temps (1806, 1807 and 1808). In 1813 Monteiro da Rocha published the *Taboas Astronomicas* (Astronomical Tables) (Coimbra, 1813), that would be the basis for calculating the EAOAUC until the mid–19th century[4].

## 3 Conclusion

The establishment of the university's astronomy teaching and the creation of OAUC were remarkable steps in the institutionalization of astronomical science in Portugal. The conception and erection of the OAUC was not limited to that of a typical university observatory. Above all, with a well–defined program for the elaboration and publication of the Astronomical Ephemeris, the OAUC becomes a national scientific institution and an unavoidable national reference. The contribution of Monteiro da Rocha was structural for the advancement of Portuguese astronomy, because he established the mathematical methods and astronomical practices essential for the training of the future Portuguese astronomers and cartographers of the first half of the nineteenth century.

Monteiro da Rocha was responsible as well for the conception of a measuring device for the triangulation and measurement of the geodesic works carried out in Portugal at the end of the 18th century (firstly in the geodesic works of 1790–1794 and again in 1835).

[4] The first volumes of the EAOAUC were calculated using the astronomical tables published by Lalande in the 3rd edition of his Astronomy (1792) (except the positions of the planet Mars that were calculated using some tables composed by Monteiro da Rocha himself in 1802). The positions of the Sun and Moon, published, between 1807 and 1813, in the EAOAUC, were calculated upon the tables of Burg and Delambre, published by the Bureau des Longitudes in 1806.

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# Ludwik Silberstein in Italy

**Piotr Flin and Włodzimierz Godłowski**

**Abstract.** Ludwik Silberstein (1872–1948) was the Polish–American scientist who worked in many branches of physics, but he is remembered mainly due to his work in general relativity. We present the influence of Ludwik Silberstein when staying as *libero docente* (in Italy until 1970, private *docentship*) in Bologna and Rome Universities (1899–1904, 1904–1920 respectively) on his scientific development and further career.

Key words: Silberstein, Physics, Docentship, Bologna, Roma

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## 1 Early days of Ludwik Silberstein: Scientific Career

Ludwik Silberstein was born in Warsaw on 15 May 1872. By the historians of science he is described as Polish–American mathematical physicists. When Silberstein was born, Poland was not existing as an independent country. It was divided among Imperial Russia, Prussia and Austro–Hungarian empire. His registered given name was Lazar. His father Samuel Silberstein was a merchant in Warsaw, while his mother was Emilia Steinkalt (u.d.). He had elder brother and sister. Both studied and obtained doctorate from Chemistry (1882 Tuebingen) and Philosophy (1902 Zurich) respectively (Duerbeck and Flin 2005; Flin and Duerbeck 2006). Lazar attended the school in Warsaw (Russian Empire) and after that in Cracow (Austro– Hungarian empire). At the end of the secondary school he changed his name into Ludwik. Inscribing to the Jagiellonian University in Cracow in 1890, being in the last class of the school, he use the name Ludwik and wrote clearly two important points of his CV, namely religion: Jewish, nationality: Polish. He studied for one year in Jagiellonian University in Cracow, after that also one year in Heidelberg and he terminated his studies in Friedrich Wilhelm University zu Berlin, when he presented doctoral thesis: *Ueber die mechanische Auffasung electromagnetischer Erscheinungeg in Isolatoren und Halbleitern* (1894). The opinion on the work written by both referees, i.e.: Max Planck and Herman von Helmholtz is: sollertiace et ingenii laudabile.

After studies, Ludwik Silberstein obtained assistant position in Lemberg Politechnical School for one year. He was Russian subject, while Lemberg (Lvov) belonged to Austro–Hungarian Empire, so it was very difficult for such person to obtain permanent university position and Ludwik Silberstein did not succeed to obtain it. Later, Ludwik Silberstein spent two years in Warsaw, working in an optical firm. He was active scientifically, writing 14 papers between 1892 and 1899. Moreover, he translated several books.

## 2 Silberstein, Professorship in Italy

In 1899 he started a new period of his life. He became a lecturer in mathematical physics in Bologna University. He took this position till 1904, when he moved to University of Rome, taking the same position, *libero docente*, in the same subject. Practically till the end of his affiliation with Rome, which was 1920, he delivered every year some courses of theoretical physics. In 1913 he moved to London, delivering lectures on general relativity in University College. The main reason of this change was the fact, that he thought that colleagues are too much interested in his wife, Rose.

**Fig. 1** Dr Ludwik Silberstein[1]

**Fig. 2** Mrs Rose Silberstein

He was very talented for languages, but had a lot of problems with English pronunciation. Therefore, his teaching period in London was rather short. He entered Adam Hilgar Ltd, as scientific advisor where he was not in the editorial part of the company, but he was engaged into scientific instrumentation. During the WWI he was connected with the British War Office, but still also lectured in Rome. This work caused that in 1920, Ludwik Silberstein became British subject. The same year he left UK, went to USA as a leading scientific advisor of Eastman Kodak in Rochester, where he worked till the end of his live in 17 January 1948.

The period of his stay in Italy was very important for his development and scientific career. Silberstein prepared his lectures very carefully and after some additions they were published as a book. For example its happened with *Ellectricita and Magnetismo, corso teoretico tenuto nella*

[1] Autochrome (c.1915). With courtesy of George Eastman House, International Museum of Photography and Film. *Ibidem* for the Fig 2.

*R. Universita di Bologna 1900 – 1901*, published in 1905, which after that constituted a part of his Electricity and Magnetism, published both in English and Polish. He was the author of the famous *Theory of relativity* (London 1914 and 1922), *Vectorial mechanics* (1913) and other textbooks. His scientific interests were very broad. They were connected with both pure and applied physics. The examples are the following papers: *Molekulartheorie der Laiter, Halnleiter und Isolatoren, Quelques remarques sur la vapour satureequaternionic relativity* (1913). *Radiation from an electric source and line spectra, multiple reflection* (1916), *Motion of the perihelion of Mercury deduced from the classic theory of relativity* (1917). These papers were related to different subjects of physics like electricity or problems of theory of relativity. Moreover it should be pointed out that paper *Motion of the perihelion of Mercury deduced from the classic theory of relativity* was important to his future discussions with Einstein about movement of two bodies system in general relativity. His papers were of interest to many researchers as well as historians of science. It is mostly because he anticipated some ideas which were studied in their full potential many years later. For example Jammer (1966) described in the following words the two papers of Silberstein (*symbolishesche Integrale der electromagnetischen Gleischungen, aus den Andeutung zu einer allgemainen Theorie der Physikalischen Operatores* (1901) *Versuch einer Theorie der physikalischen Operatoren* (1903)).

> Ludwik Silberstein, which anticipated to some extent the formal aspects of the operational approach in modern quantum mechanics. The study of symbolic integrals of the equations of the electromagnetic field suggested to Silberstein, who is known mostly for his writings on the theory of general relativity, a theory of „physical operators" in terms of which he attempted to give a unified representation of such disparate phenomena as mechanical oscillations, heat conductions and electrodynamical processes.[2]

In fact Ludwik Silberstein introduced the notions of state and superposition of state as well as gave numerical details, which appeared in matrix quantum mechanics 25 years later (Jammer 1966).

Moreover Silberstein papers: *O tworzeniu się wirów w płynie doskonałym* 1896, *Enstehung von Wirbelbewegungen in einner*

[2] Jammer 1966.

*reibungslosen Fluessigkeit* 1896, quoted by Bjerknes, anticipated the Bjerknes circulation theorem (Bjerknes 1898; Thorpe, Volkert and Ziminski 2003; Bialynicki–Birula 2005). Ludwik Silberstein initiated a line of thought involving eddy currents in the atmosphere, or fluids generally because Silberstein anticipated foundational work by Vilhelm Bjerknes (1862–1951). Bjerknes theorem is about the formation of eddies in the perfect fluid they do not form only if the pressure p is the function of the density ρ i.e. surfaces p and ρ coincide with each other.

In 1896 Ludwik Silberstein, used Schütz's extension of Helmholtz's vorticity equations to consider the case of the emergence of rotation in a nonhomogeneous fluid that initially has no such rotation. He considered a gas in which pressure and density surfaces may not coincide, which of course is the case in the atmosphere (Thorpe, Volkert and Ziminski 2003).

One of (maybe the only one) the results of Silberstein which is still important for modern physics is Riemann–Silberstein vector is a multivector that combines the electric field (E) and the magnetic field (B) (Bialynicki–Birula 2005); it was introduced in the paper *Elektromagnetische Grundgleichungen in bivectorieller Behandlung* (Annalen der Physik 22, 579, 1907). Unlike the Poynting vector it has physical meaning only in the quantum interpretation of Maxwell equations, as a photon wave function. It is defined as: $\vec{F} = \vec{E} + i\vec{B}$ . After multiplying the Maxwell equations by the Dirac constant, it enables us to interpret their dynamical part as a Schrödinger equation for photon. Recently Bialynicki–Birula (Bialynicki–Birula 2005) and Bialynicki–Birula and Bialynicka–Birula (Bialynicki–Birula and Bialynicka–Birula 2012) argued that the use of the Riemann–Silberstein vector greatly simplifies the description of the electromagnetic field both in the classical domain and in the quantum domain. In their review they describe many specific examples where this vector enables one to significantly shorten the derivations and make them more transparent. They also argue why the Riemann–Silberstein vector may be considered as the best possible choice for the photon wave function.

## 3 Conclusion

The stay in Italy was very fruitful for the scientific development of Ludwik Silberstein. This stay allowed him to continue scientific career. Probably here, his main ideas grew up. He quite high estimated this period. In all his books written and published well after leaving Italy, below his name, as an author he always added the inscription *formerly the lecturer in mathematical physics at the University of Rome*. Such inscription is seen at the 2nd edition of his General Relativity, as well as books Causality (1932) and his last book: *Discrete spacetime* (1936). We would also like to point out that during Italian period of his life he continued to have close relation with several Polish scientists.


## Acknowledgments

We thank numerous archives for their kind and fruitful approach to our work, especially of the Universities: Berlin, Cracow, Heidelberg, Lvov, Rome. Our investigation of live and scientific career of Ludwik Silberstien is a continuation of research made together with late Dr. Hilmar W. Duerbeck (1948–2012).


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# Court Engineering in Ptolemaic Alexandria

**Helen Fragaki**

**Abstract.** The works of Ktesibios, Philo and Hero show that the use of abstract principles for technical purposes had been widely practiced in the Alexandrian Museum and Library since the 3rd c. BC. This paper explores the political, religious and ideological issues of these practices, especially their relationship to the process of the divinisation of kings, which started during this period. The eminent role of applied science, which was perceived as an extension and a proof of the rulers' divine power, explains why the transgression of the opposition between theoretical research and mechanics was overcome in the realm of court engineering.

Key words: Alexandrian engineering, Artillery, Automata, Hero of Alexandria, Hydraulics, Ktesibios, Philo of Byzantium, Royal propaganda

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## 1 A Short Introduction

Since the 3rd c. BC, the use of abstract principles for technical purposes was particularly developed in Alexandria. As recent research has shown, the works of Ktesibios (BC 290 – BC 250) Philo of Byzantium (ca BC 240 – BC 200) and Hero of Alexandria (ca. 62 AD) definitely tend to span the gap between high–level geometrical demonstrations and mechanical techniques (Prager 1974; Tybjerg 2004, 2005). However, the historical circumstances in which these new approaches evolved have not yet been explored in relation to the evolution of the tension between theoretical and applied research. The aim of this paper is to show that the transgression of this opposition had a strong political and religious background, especially in connection with the divinisation and cult of the rulers during this period.

Indeed, the dual character – both theoretical and technical – of Alexandrian engineering needs to be associated with the material and institutional conditions in which it developed. The Library and the Museum, established by the Ptolemies during the first half of the 3rd c. BC, located within the royal court and placed under the patronage of the king, put scholars from different fields constantly in contact with each other and gave them access to all branches of knowledge. Therefore, the boundaries between different disciplines could easily be transgressed, and many renowned scientists adopted a global, interdisciplinary approach. Thanks to the interaction between intellectual practices, the usual dichotomy between pure and applied science was no longer so pronounced. Moreover, the Ptolemies tried to collect as many books and as much scientific information as possible, in order to lay claim to possessing the entire world's memory and cultural heritage (Schürmann 1991; Jacob 1998). This universal ambition rendered discriminating between different sources of knowledge meaningless and the opposition between theoretical and practical concerns redundant.

## 2 Mechanics as an Instrument of Royal Propaganda

Although the practical use of abstract principles in this cultural context has already been considered from an epistemological point of view in recent literature, it has not been related to ideological issues such as the consolidation of the divine rule and power of the dynasts. Philo provides direct evidence for this relationship in his *Belopoieca*, where he explicitly associates the exceptional progress in the field of siege–craft and artillery construction with royal patronage (Prager 1974):

> Later engineers drew conclusions from former mistakes, looked exclusively for a standard factor with subsequent experiments as a guide and introduced the basic principle of construction, namely the diameter of the circle that holds the spring. Alexandrian craftsmen achieved this first, being heavily subsidized because they had ambitious kings who fostered craftsmanship. The fact that everything cannot be accomplished by the theoretical methods of pure mechanics but that much is to be found by experiment, is proved especially by what I am going to say.[1]

In this quote, technical skills are not considered as inferior or subordinate to pure science, but are thought to generate theoretical conclusions, which had never been reached before. Thanks to the backing of the Ptolemaic court, experimental mechanics is clearly viewed as a vehicle for further scientific discoveries.

Other ways in which mechanics has been used for royal propaganda are obvious, but have not been regarded and evaluated as parameters of the relationship between pure and applied science. The interrelations between epistemological concerns and official ideology therefore require further examination. In fact, technical research could be used to enhance the king's authority and public image, as literary evidence suggests: an epigram by Hedylos written in the 3rd c. BC could be cited as an example. These verses clearly attribute to Ktesibios the creation of a magical *rhyton*, a ritual vessel for libations in the shape of the Egyptian god Bes, which produced a pleasant whistle when wine was poured into it. According to the poem, this device was in the temple of the queen Arsinoe, who was deified after her death (Schürmann 1991; Fragaki 2012):

> Come, lovers of strong wine, and behold this rhuton / in the temple of the venerable Arsinoe, dear to / the West Wind; / it represents the Egyptian dancer Besas, who / trumpets a shrill / blast when the stream is opened up, allowing the/ wine to flow [...] / But honor this clever invention of Ctesibius – / come, young men!–in this temple of Arsinoe.[2]

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[1] Philo, *Belopoeica* 50, 21–29. See Marsden (Marsden 1971, pp 106–109).

[2] Athenaeus, *The Learned Banqueters* XI, 497d–e. See Olson (Olson 2009, pp 420–423).

The vessel is not presented as a mere trick deceiving the audience's senses, but as an ingenious invention of the famous court engineer, who is praised for his contrivance, which is capable of reproducing sound. This amazing effect therefore reveals an extraordinary capacity to manipulate and imitate natural phenomena, which is shared by the divine Arsinoe to whom the temple was dedicated. The colossal mobile statue of Bacchus' nurse Nysa, described by Callixenus as part of the spectacular procession which took place in Alexandria during the reign of Ptolemy II, provides further evidence for such inventions which were used for royal propaganda to display the kings' almost supernatural power. By reproducing movement or sound, both of which are characteristics of living beings, the sovereign appeared to have the power of a god to imbue inanimate matter with life. Automatic theatre also demonstrated the sovereign's dominion over nature through a series of astonishing effects, which included animated figures suddenly appearing or disappearing. The performance entitled "Nauplius' Legend", created by Philo according to Hero's text dealing with the same subject (Prager 1974; Von Hesberg 1987; Schürmann 1991; Fragaki 2012), exalted the figure of the engineer not only through its brilliant contrivances but also through its plot, which was based on the story of Palamedes, the mythical inventor who took part in the siege of Troy.

Other inventions and techniques, which had purely practical purposes, such as hydraulic devices for agriculture and the water supply, as well as levers or harbour building, mentioned as part of Philo's *Mechanical System* (Prager 1974), were also meant to satisfy the dynast's desire to subdue natural forces, deal with military or environmental dangers and establish control over the physical and social surroundings. The pioneering works of this engineer have only partly survived, but Hero, who is his direct intellectual descendant, definitely appeals to a sovereign who desires full control over the outside world and his devices are presented as means of dominating both the physical and the political environment through mechanical and geometrical expertise. He seems to be borrowing the language of royal political discourses that probably date back to the Ptolemaic period – though still valid in Imperial times – when he refers to issues of military defence, security and social order and connects mechanics with ethical values, such as the equal distribution of wealth, justice and fairness (Schürmann 1991; Tybjerg 2004). Hero goes so far as to argue that peace, not only in the political and social sense of the term but also as a state of mind, can be more readily achieved through mechanics than through philosophical thought (Tybjerg 2005):

> The largest and most essential part of philosophical study is the one that concerns tranquillity [...] and I think research about tranquillity will never reach its goal through rational arguments. But mechanics has surpassed teaching through reasoning on this score and taught all human beings how to live a tranquil life by means of artillery construction. By means of it, when in a state of peace, they will never be troubled by reason of resurgences of adversaries or enemies, nor, when war is upon them, will they ever be troubled by reason of the philosophy which it provides through machines…they will remain tranquil in their consciousness of security [...].[3]

This audacious assumption suggests how machines could have enabled the sovereigns to present themselves as enlightened monarchs generously dispensing philosophical values as essential as peace of mind to the citizens.

## 3 Conclusion

During the Ptolemaic period mechanics was regarded as having a status equal to that of theoretical science as it provided the monarchy with the necessary means for achieving overall military, political and social control, which was crucial if the rule of the dynasty was to be efficient and remain unchallenged. Technical achievements were used to demonstrate the supernatural power of the dynasts who where gradually assimilated to divinities during this period and worshipped after their death in temples such as the Temple of Arsinoe where Ktesibios' magical vessel was kept. Like a god on Earth the king appeared as the master of natural elements, either subjugating them by reorganizing at will and dominating the physical and social environment, or imitating them by reproducing their effects. Thus, applied science served to legitimise the royal power and support the ideological discourse associating the sovereign's rule over his kingdom with the gods' dominion over the universe. Moreover, it allowed the king to present himself as a guarantor of peace and security but also as a magnanimous governor ensuring the citizen's tranquillity. Mechanics therefore seems to have been regarded as an extension and a proof of the

[3] Hero, *Belopoeica* 71–73.5 See Tybjerg (Tybjerg 2005, p 217).

divine power of the rulers, enhancing their image and consolidating their strength. This eminent role explains why the opposition between theoretical research and mechanics was overcome in the realm of court engineering.

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# Field Equations or Conservation Laws?

**Mauro Francaviglia, Marcella Palese and Ekkehart Winterroth**

**Abstract.** We explicate some epistemological implications of stationary principles and in particular of Noether Theorems. Noether's contribution to the problem of covariance, in fact, is epistemologically relevant, since it moves the attention from equations to conservation laws.

Key words: Being, Becoming, Conservation laws, Field theory, Noether's Theorems

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## 1 Field Equations Dual to Stationary Principles

We are interested in the study of the relation between symmetries (i.e., invariance properties) of field equations and corresponding conservation laws, more precisely, in the investigation of some aspects concerning the interplay between symmetries, conservation laws and *variational principles*.

As is well known, the theory of General Relativity appeared after Albert Einstein's (1879–1955) struggle, during the years 1912–1914[1], whether founding his theory on the covariance of field equations or rather on the covariance of the conserved quantities (Einstein and Grossmann 1913). David Hilbert (1862–1943) also dedicated his study to this important question as testified by Emmy (Amalie) Noether (1882–1935) in the end of her famous and celebrated paper *Invariante Variationsprobleme* (Noether 1918) in the section titled *Eine Hilbertsche Behauptung* (Noether 1918, p 253).

In this short note we intend to underline some overlooked, however fundamental, aspects and implications of E. Noether's contribution to the problem of energy and in general of conserved quantities in field theories. Noether's contribution to the problem of covariance, in fact, is epistemologically relevant, since it moves the attention from equations to conservation laws, founding the theory on the invariance of the *action* (i.e., of the Lagrangian).

Accordingly, in a very recent paper (Francaviglia et al. 2013) we studied Noether conservation laws associated with some *variational* invariance of global Euler–Lagrange morphisms associated with local variational problems of a given type. In this context, the question arises whether we should be interested in conservation laws different from those directly associated with invariance properties of field equations. The answer to this question relays on Emmy Noether's paper.

As is well known, in fact it was motivated by the fact that, although the gravitational field equations were global, the associated conservation laws found by Einstein by a nonvariational approach were not (think of the well known energy–momentum *pseudo–tensor*). Explicitly, in the introduction of her paper, Noether wrote:

[1] Within the collaboration with Marcel Grossmann (1878–1936).

> Concerning these differential equations that arise from problems of variation, far more precise statements can be made than about arbitrary differential equations admitting of a group, which are the subject of Lie's researches.[2]

The relevance of the study of differential equations generated by an invariant variational problem in its whole is in the issue of a major refinement in the results: to symmetries of equations could correspond conservation laws which have a nonvariational meaning and thus could not be characterized in a similar precise manner.

Sometime it is improperly stated that Noether's Theorem would be *formulated for Euler–Lagrange equations in field theory*. Instead, it is important to stress that Noether's I and II Theorems actually are statements about the invariance of a variational problem with respect to a finite continuous group of transformations and an infinite continuous group of transformations, respectively. The direct object of Noether's investigations are what she calls "Lagrangeschen Ausdrücke; d.h. die linken Seiten der Lagrangeschen Gleichungen" (Noether 1918), which we shall call hereafter Euler–Lagrange expressions. *The accent is not put on field equations* although her results have, of course, *also* consequences concerning invariance properties of equations. It is maybe noteworthy that all Noether considerations are made *off shell*, i.e., not along solutions of Euler–Lagrange equations. It is also important to stress that Noether immediately considers the formulation of a variational problem at the infinitesimal level of "integralfreie Identität" (Noether 1918, p 237).

Noether's Theorem II is in fact concerned with a variation of the Euler Lagrange expressions. Symmetry properties of the Euler–Lagrange expressions play a fundamental role since they introduce *a cohomology class which adds up to Noether currents*[3]; they are related with invariance properties of the first variation, thus with the vanishing of a second variational derivative. The concept of a variation of Noether current is then clearly involved. In line with Lepage's cornerstone papers (Lepage 1936a, 1936b), which pointed out the fact that the Euler–Lagrange operator is a quotient morphism of the exterior differential, we consider a geometric

[2] "Über diese aus Variationsproblemen entspringenden Differentialgleichungen lassen sich viel präzisere Aussagen machen als über beliebige, eine Gruppe gestattende Differentialgleichungen, die den Gegenstand der Lieschen Untersuchungen bilden". Translated from German by M.A. Tavel (Tavel 1971).

[3] A formulation in modern language of Noether's results.

formulation of the calculus of variations on fibered manifolds for which the Euler–Lagrange operator is a morphism of a finite order exact sequence of sheaves. The module in degree (n+1), contains so–called (variational) dynamical forms; a given equation is globally an Euler–Lagrange equation if its dynamical form is closed in the complex of global sections (Helmholtz conditions) and its cohomolgy class is trivial. Therefore, symmetries of Euler–Lagrange morphisms or, more generally, of so–called variational *dynamical forms* are considered insomuch as they can provide informations about Noether currents of some potential Lagrangians, also in the spirit of the Bessel–Hagen version of Noether's Theorem II (Bessel–Hagen 1921).

## 2 *Being* and *Becoming*: a Contemporary Perspective

As we said, Emmy Noether clearly pointed out how, considering invariance of *variational* problems, a major refinement in the description of associated conserved quantities is achieved.

In spite of the enormous amount of literature on the applications of the Noether Theorem I (Markov processes, engineering, material sciences, signal propagation and so on); lesser study instead is dedicated to the second part of Noether Theorem. Natural and gauge–natural classical description of field theory is given in terms of generalized Bianchi identities by physicists (Bergmann 1949)[4], thus revealing an underlying epistemological position aiming to give relevance to equations (although variational) rather than to conservation laws. The ensuing problem of the non covariance of the latter seems to have (according with Einstein final epistemological position) a secondary importance: conserved quantities can be always somehow suitably covariantized (think of the Komar superpotential), e.g., introducing some kind of background. Therefore, the epistemological relevance of Noether's approach to the study of field theory has not yet been completely uncovered in all its implications.

In order to explicate them, in (Francaviglia et al. 2012) we introduced the new concept of conserved current variationally associated with locally variational invariant field equations. The invariance of the variation of the corresponding local presentation is a sufficient condition for the current being variationally equivalent to a global one. We considered Noether

[4] Without quoting the original strictly related Noether's result! Peter G. Bergmann (1915–2002).

conservation laws associated with the invariance of global Euler–Lagrange morphisms generated by local variational problems of a given type. The underlying idea is that of looking for conservation laws coming from invariance properties of a (*possibly local*) Lagrangian (rather than a field equation solely) to find a way of associating global conservation laws with the gravitational *field*.

As already stressed, in order *to understand the structure of a phenomenon described by field equations*, one should be interested in conservation laws more precisely characterized than those directly associated with invariance properties of field equations. Thus, it is of fundamental importance to seek for conservation laws coming from invariance properties of a (*possibly local*) variational problem in its whole (rather than a field equation solely) to find a way of associating global conservation laws with a local Lagrangian *field* theory generating global Euler–Lagrange equations.

From Physics' point of view, *field equations* appear to be a fundamental object, since they *describe the changing* of the field in base space. Somehow, physicists are generally well disposed to give importance to symmetries of equations, because they are transformations of the space leaving invariant the description of such a change which is provided by means of field equations. On the other hand the possibility of formulating a variational principle (i.e., a principle of *stationary* action) – from which *both* changing of fields and associated conservation laws (i.e., quantities not changing in the base space) could be obtained – has been one of the most important achievements in the history of mathematical and physical sciences in Modern Age. It allows, in fact, to keep account of *both* what (*and how*) changes and what (*and how*) is conserved. In the variational calculus perspective, we could say that *Euler–Lagrange field equations are "adjoint" to stationary principles up to conservation laws: a* contemporary mathematical formulation of the duality between *Being* and *Becoming*.

## 3 Conclusion

In a famous paper sir Michael Francis Atiyah wrote:

> Standard text–books make great play with the technical details, introducing coordinates, writing equations and then showing that the resulting physics is independent of the choice of coordinates. To a

> geometer this is perverse. The fundamental link is from physics to geometry, from force to curvature and the algebraic machinery that encodes this is secondary. God created the universe without writing down equations![5]

Thus if *god created the universe without writing down equations* the epistemological position of choosing invariants versus equations can be even strengthened: we assume the field to be described by a strong stationarity condition, requiring more than the invariance of the action, even the invariance of the first variation: this enables us to define a global conserved current associated with invariant field equations.

In this perspective in (Francaviglia et al. 2013) we found that the conserved current associated with a generalized symmetry, assumed to be also a symmetry of the variational derivative of the corresponding local inverse problem, is variationally equivalent to the variation of the strong Noether currents for the corresponding local system of Lagrangians. Moreover, if the variational Lie derivative of the local system of Lagrangians is a global object, such a variation is variationally equivalent to a global conserved current.

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[5] Atiyah 2005, p 2041.

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# "... May God Protect You from Lightning ..."

**Arturo Gallozzi**

**Abstract.** This study analyzes one of the first, and most important, installations of a lightning conductor system in Italy, applied to a monumental complex: the Abbey of Monte Cassino, in Southern Lazio. This study – in addition to a profile of the designer of the system, Feliciano Scarpellini (1762–1840) an astronomer and professor of physics, a leading scholar and scientific investigator in Italy during the late eighteenth and early nineteenth centuries, the founder, among other things, of the *Accademia Caetani*, which later became the *Accademia dei Lincei* – analyzes the relief and planar–altimetric arrangement of the lightning rods, which, together with other partially unpublished documents, provides several important measurements of the Abbey, which, completely destroyed by ferocious combat during the Second World War, left little graphic evidence that describes it geometrically. It also outlines the profiles of other scholars who contributed in various ways to pre–war lightning–rod system installations.

Key words: Abbey of Monte Cassino, Lightning rods; Feliciano Scarpellini; Angelo Secchi; Francesco Denza

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## 1 A Short Introduction. The Lightning–Rods of the Abbey of Monte Cassino

As attested by the words attributed by popular tradition to Arnolfo di Cambio, who, after designing an imposing foundation system consisting of many deep wells beneath the church of Santa Maria del Fiore in Florence, said “I have protected you from earthquakes, may God protect you from lightning” (Sacchi 1839, p 402), the protection of monuments from lighting was a problem that took designers a long time to solve. It was only with the eighteenth–century discovery of the dispersive power of spikes that it became possible to construct efficient, structured systems to protect against harmful lightning bolts. The Benedictine chronicles tell how the abbot Desiderius – the future Pope Victor III – while rebuilding the basilica of Monte Cassino, flattened the peak of the mountain through “igne ferroque”, in the hope of reducing the effects of lightning strikes (Carbonara 1979, p 48). In regard to these events, the testimony of Erasmo Gattola, the monastery’s archivist and historian, is significant. He tells the story of seven lightning bolts that struck the Abbey in a single hour on February, 20th 1712. The annals of the Abbey provide us with many accounts of the serious human and structural damage caused by such bad weather events on the monastery over the centuries. As a result of these repeated events, the Abbey became one of the first grand Italian monuments to be fitted – from the beginning of the 1800s – with an innovative lightning rods system (Paoloni 1912).

### 1.1 The designer, Feliciano Scarpellini

“His work and counsel required him to ascend temples and palaces to protect them from the threat of lightning with a thousand Franklin rods” (Proja 1852, p 290). Thus one of Abbot Scarpellini’s many scientific merits are recorded in priest Salvatore Proja’s (Rome 24 March 1852) eulogy (Proja 1852). The abbot was an authoritative scholarly figure at the turn of the 18th and dawn of the 19th century. He was born in Foligno on 20 October 1762. He was the son of Filippo and Caterina Piermarini, the sister of the renowned architect Giuseppe. He was first a student, then he became a teacher at the Umbro–Fuccioli College of mathematical physics in Rome. He was the Rector from 1794 to 1800. He availed himself of the support of Gaspard Monge (1746–1818) a French mathematician posted to Italy on behalf of the Executive Directorate. He was removed from the

Academy, which was subsequently suppressed, in 1800 for alleged Pro–German sympathies, backed up by French participation in the Roman Republic of 1798–1799, with the post of commanding officer. All the instrumentation of the laboratory attached to the Academy, which Scarpellini had paid for himself and in many cases built personally, was transferred to la *Specola Caetani*, the first astronomical observatory established in Rome by the Duke Francesco Caetani (1738–1810) at the family home in Via Botteghe Oscure, in 1801. Feliciano Scarpellini, Director of the Caetani science laboratory from 1797 to 1814, founded the Caetani Academy, subsequently named *New Lincei (*1807), in 1801 with the help of Francesco Caetani and Joachim Pessuti, in continuity with the Academy founded in 1603 by Francesco Cesi. In the years 1811–1813, as a Member of the Legislative Body of Paris, he was involved in the period of scientific–regulatory renewal wanted by the new rulers of France, taking a specific interest in the metric system. To this end, he designed precision scales, for which he was awarded a gold medal by Napoleon I. With the Papal restoration in 1816, Pope Pius VII awarded him the Professorship of sacred physics and astronomy at University of Rome la Sapienza, as recommended by Cardinal Consalvi, to counter the materialistic and positivistic theories deriving from enlightenment. The course was divided into six sections, one for each day of creation, according to the account of Genesis: he taught until his death in Rome on 29 November 1840. In 1823 Leo XII appointed him head of the newly established Astronomical Observatory, planned during the reorganization of University studies at the Archiginnasio Romano. Shortly before his death, Feliciano became concerned about the possibility of losing his Astronomical Physics Observatory and so in 1840 sold his extensive collection of *Physical, Mechanical, Astronomical Machines* for 1,000 *scudos* to the Apostolic Chamber and it was subsequently deposited at the Laboratory of Physics at la Sapienza.

## 1.2 The installation

The lightning protection system, installed in August 1829 at the Abbey of Montecassino under the direction of Scarpellini, has put an end to a long history of damage caused by the surge of lightning that repeatedly struck the monastic complex (Caravita 1870, p 596). Of particular interest is the explanatory *Parafulmini di Montecassino* diagram, which illustrates the treatise, *On the lightning rods of Montecassino*. Written by Filippo Maria

Pagano[1], (1797–1856) Captain in the Corps of Engineers, the treatise describes the complex construction of the lightning conductor system and supplies rare insights into the layout and structure of the Abbey prior to its complete destruction.

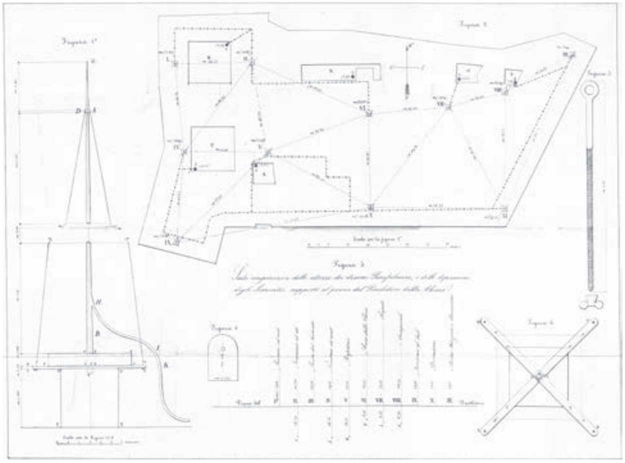

**Fig. 1** Drawing with particulars relating to the *Parafulmini di Montecassino*[2]

The constructive and typological aspects of lightning conductors installed, and their respective planimetric position are transcribed, in detail, in compliance with other available plans of the Abbey. Of note are the measurements relating to the positions of the lightning rods, calculated relative to the reference plan for the church’s presbytery (at 513.84 metres above sea level). These allow us to determine precise measurements of the heights of the various monastery structures. The installation covers a total area of about 2030 m$^2$ of the monastic complex; Scarpellini uses eleven *electric rods* for protection against atmospheric discharges, and

[1] With the pamphlet *Memoirs concerning the construction of lightning–rods published by order of the Government* (Naples, Reale Tipografia della Guerra (Royal Printing of the War), 1842) Pagano, on behalf of the Ministry of War and the Navy of the Kingdom of Naples, translated the measures adopted in France concerning the prevention of lightning bolts.

[2] It is divided into six figures, represented in appropriate graphic scales. (Pagano 1843).

specifically, the rods marked in drawing numbers VI, VII, VIII, which identify the summit points of the pediment of the basilica, the dome and the bell tower. In his essay, Pagano investigates the *sphere of action* of the lightning rods, verifying the principle followed by Scarpellini in the distribution of individual elements, comparing it with the main theories of physics at the time. Analyzing the differences of *sphere of action* defined considering the heights of the lightning conductor calculated in a *relative* (only the height of the rod) or *absolute* (including the share until the surrounding terrain) sense, there are particularly significant differences in some cases. The efficiency of the system at Montecassino is evaluated where the distribution of individual elements is conditioned by the specific location and elevation of several factories that form the structure.

## 1.3 How the system developed

The system of lightning–rods of the Abbey of Monte Cassino, which was then cutting–edge technology, preserved in its original form for forty–seven years, and then underwent many changes in the following decades due to the development of meteorology and inevitable wear and tear.

In 1876, following a visit to the Meteorological Observatory of Monte Cassino and an exchange of views with the director and founder, P. Quandel, Father Angelo Secchi[3] set out his thoughts and solutions regarding the Abbey's lightning–rod system in a letter to the abbot of Monte Cassino called D'Orgemont (1826–1896). This examination is the result of a sample analysis of one of the conductors (descending) and

[3] Angelo Secchi (1818–1878), a Jesuit, was a mathematics and physics teacher in Loreto in 1841 (Denza 1879, pp 1132–1137). In 1849 he was put in charge of the Collegio Romano (Roman College, Italy) observatory. The 1864 Italian scientific yearbook described Angelo Secchi as an astronomer, meteorologist, physicist, chemist, mechanics expert, analyst, engineer, geographer, hydraulics expert, and archaeologist. Father Angelo Secchi's activities and scientific work were varied and extremely valuable: in the field of meteorology his fame is linked to the invention of the meteorograph. He further distinguished himself in the then new field of spectroscopic astronomy. "The spectroscope: Here is the instrument used by Fr. Secchi for his studies into the composition of stars– an instrument as revolutionary to our exploration of celestial bodies, as the discovery of the compass was for the exploration of our own world" (Bellino Carrara 1918, p 7).

testimonies collected from the monks on the phenomena that occurred during thunderstorms.

Secchi pointed out that the main defects of the Scarpellini system were the eleven lightning–rods, which were considered insufficient for the Abbey, the single tip the lightning–rods were connected to and corrosion of the conductors over time. The conductors were also considered insufficient, since there were only six of them for eleven lightning–rods and, moreover, they were not all connected together. He also thought that there was not enough metal buried under the surface which, together with the rocky nature of the soil, did not guarantee a good dispersion. This report in the form of a letter from Secchi then provides a list of suggested improvements for the enhancement of the system: the use of copper instead of the all–iron conductors, lightning–rods with at least six tips, and a different positioning of the poles on the roofs, so as to protect their tops and protruding angles.

## 2 Conclusion

The improvements suggested by Secchi, who personally directed the work at Monte Cassino, were carried out in a short time and they ensured a decade of tranquillity for the Abbey. In the period 1887–1888, damage to the Abbey by particularly strong bolts led to additional measures to upgrade the lightning–rods system. The correspondence between P. Denza[4], who was also invited to visit Monte Cassino for a site survey, and

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[4] Francesco Maria Denza (1834–1894), a Barnabite, a student of the seismologist Timoteo Bertelli, was involved in meteorology, climatology, astronomy and seismography. He met Angelo Secchi In Rome, which fuelled a passion for geophysics. In 1859 he founded a meteorological observatory at the Royal College of Moncalieri. He was soon able to create a network of observers in Italy and South America, also with the cooperation of Salesian missionaries. Starting in 1866, the data collected by observers was published in the *Meteorological Bulletin of the Carlo Alberto Royal College Observatory in Moncalieri*. The magazine, which was published on a monthly basis, was inspired by a similar publication of the Roman College Observatory, which Secchi had been in charge of since 1862. In 1875 he and Angelo Secchi were both members of the Italian Meteorology Governing Council. In the last years of his life he promoted the revival of the Vatican observatory, which he took charge of and

P. Quandel, tells us that in 1888 the Abbey had thirty lightning–rods, of which sixteen were obliquely located at the corners. The old single tips of the Abbey's dome, bell tower and cross were replaced with platinum ones with four elements in a radial pattern, manufactured by the firm Cravero of Turin. Other works were carried out in 1892: an increase in the number of lightning–rods, connecting them with copper wire on the roofs; changes to the number and type of traps, replacing those made of iron or iron and copper with only copper ones; the connecting of the traps two metres below ground. These changes brought the number of lightning–rods to forty, which remained unchanged, although Paoloni had them further improved in 1927. The platinum tips, which were partly or completely melted by lightning bolts, were replaced by new lightning–rods manufactured by the firm Borghini of Arezzo, equipped with a variable number of needles, with a minimum of forty, whose yield was optimal, since they could not melt.


**Fig. 2** (l) Scarpellini, located on the Pincio in Rome; (m) Secchi[5]; (r) Denza[6]

As well as causing the complete destruction of the Abbey, the catastrophic events of World War II put an end to a glorious period in which the

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where he worked until he died in 1894. The monthly bulletin underwent significant reductions in terms of frequency, content and consistency, until it merged in 1931 with Meteorology Practice, a magazine edited by the Monte Cassino monk Bernardo Paoloni (Giannuzzi 1934).

[5] Denza 1879, pp 1132–1137.

[6] Via: http://www.meteo.unina.it

meteorological observatory was operational. This observatory, which was founded in 1875 by the abbot Giuseppe Quandel, was then masterfully managed until 1931 by the monk Paoloni, and then – in the years prior to World War II – by the distinguished monk and engineer Don Angelo Pantoni. It was not restored after the reconstruction of the Abbey.

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# Mathematics and Narratology: Exploring the Structure of Pirandello's Novels according to the Möbius Ring

**Dimitra Giannara**

**Abstract.** In this paper firstly I give a descriptive overview of the structure of Luigi Pirandello's (1867–1936) novels in a *ringkomposition*. I subsequently replace the common knowledge of the *ring* with the one proposed by August Ferdinand Möbius (1790–1868). Finally and, as a result, we arrive to some seditious conclusions concerning what we thought to know about Pirandello's heroes. Particularly I will show that they were directing away from self–reference or formal rules by rambling inside and outside the ordinary social topology. The interactions studied by physics are in the present paper fabricated in the five–dimensional space of literature which revaluates the modern conceptions of time, space and causality.

Key words: Pirandello, Möbius ring, Incompleteness theory, Recursive definitions, Bilateral trip

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## 1 Narrative structures and Pirandello's Ring–like Composition

Literary analysis based on the classical taxonomy of *Poetry* have frequently accommodated the study of plot macrostructures on the distinction between bad/wrong or success/failure, thus on a limited two–valued classification that presumes that those notions are obvious. Modern attempts have significantly increased the number of parameters taken in consideration, even if they do not always lack of relativism: how do the four seasons ensure a safe base on which Northrop Frye has classified the plots in four as well? (Frye 1975) Why Craine's plots of thought embrace only the protagonist's thoughts and not those of the implied or real author, of the narrator or of the reader? (Crane 1952) How can Greimas' intelligent semiotic square reflect the dynamic passage from truth to false relations that the same person creates from one minute to another? (Greimas 1952) As a result we have find ourselves asking: "Are we forever condemned to Aristotle's moral presuppositions […]?" (Chatman 1978) Without expecting to find a concrete model guide, we head in the direction of not strictly content–based narrative structure analysis. We leave behind the forms of Propp's fairytails, of Todorov's *Decameron* or the Bremond model, for the fear of placing the complexities of all narratives into some pre–existent formula. We leave behind idealism and impressionistic comments as well, for the fear of an erroneous cancellation of the need of plot categorization itself. And we find ourselves strolling inside the story–space and the discourse–space that means inside the narrative space following the concrete processes that the author chooses to describe. For the necessity to delineate the novel's space, time and action from inside, as if we were silent participants of the plot, we applied a three–dimension approach of narrative analysis – step by step, in parallel and ring–like (Marchese 1990) – in which we've found many virtues. Such categorization has the privilege of pointing out more objectively the course of the facts from a more formal content point of view. It marks out the dynamic course of the chronological sequence of the events without revoking any categorization of plot–types known up to now. And, finally, it's an approach bordering the most on positive sciences which will help us overcome one–sideness and render *transparent* certain "basic relationships, patterns and cycles in the world" (Cajete 2000), and thus even in the narrative world, and in particular in the novels of Luigi Pirandello (1867–1936). The Pirandellian characters are travelling, literally or metaphorically, between strangers, they share each other's company but not a common confidence for the world they breathe in: "My travelling companion, knew quite well all that concerned him to know […] But I?"[1] They feel awkward because any calculation they make doesn't bring the result that common logic has always given. One plus one doesn't give two: it gives children, it gives conjugal betrayal, sometimes it brings back to nothing filled with loneliness or else it grows into a hundred or a hundred thousand different viewpoints. These unorthodox lessons must be spread for anyone to know. Therefore, the protagonists' journey turns out to be not only educative but pedagogic as well: the leading characters are tutoring their friends and family, all those from whom they wanted to escape at first, because they carry out a cyclical process of awareness according to which no new experience excludes old delusion or imminent madness. So they choose to travel and never to leave or quit, but to travel in meandering streets that they bring back to familiar places, because even after only half the trip, they have already realized the secret of salvation and now they dedicate all their narrative life to shout it out. Such an observation offers the first hint that Pirandello's novels are constructed on a *ringkomposition*[2]. According to this composition, the first and the final part correspond symmetrically to each other. The main motive (Barthe's *noyau*) of the narration nests other minor plot events, or even numerous *almost* situations, that they all reinforce the loop towards the final solution.

## 2 The particularity of Pirandello's Novels: the Reinvention of Möbius Ring in Literature

If we insist to examine Pirandello's novels content, we observe that the plot events perform some series of related steps over and over and abort

[1] "Quel mio compagno di viaggio sapeva bene tutto ciò che gli importava di sapere […] Ma io?" (Pirandello 2005 II, p 702).

[2] Only novel exception is *I vecchi e i giovani*, structured in parallel. Of course, many Pirandello's short–stories recall some similar Möbius representation as well, but their brief extent that transforms the description directly into narration concentrates the structure on the technique of *in ultimas res* rather than on a dynamic sequence–centred method that we propose here with the Möbius–ring model analysis. For a content–based Möbius analysis see Pickover 2006.

process when specific conditions are met. It's the basic feature of the strange loop phenomenon that occurs "whenever, by moving upwards (or downwards) through the levels of some hierarchical system, we unexpectedly find ourselves right back where we started" (Hofstadter 1999, p 10). The finishing point may then be familiar to the readers, because it is usually the same place, with the same characters that we met at the beginning. But the condition that aborts progress differs in a strangely familiar way as well. It may be a new marriage for the old Don Diego in *Il turno*. It could be the adultery committed by *L'esclusa* Marta Ajala, like a self–fulfilling prophecy of which her husband was convinced right from the start; the divorce of Silvia Roncella in *Suo marito*, even if Giustino Boggiolo has always acted the same way towards her from the start to finish; or the devoid of feeling *Serafino Gubbio, operatore* even in front of death. However, the more Pirandello's works get humoristic the more loops become free and dangerous because of the risk that the condition for abortion may never occur, leaving the narration widely open, capable to adopt real, extra textual life as well. Mattia Pascal has found a real life confirmation in Ambrogio Casati whose story Pirandello mentioned in his Advertence. The six characters of the *Sei personaggi in cerca d'autore*, initially conceived as a novel (Pirandello 1993), should be represented as coming on scene through the audience, as light entities of our world and they have to be clearly distinguished from the actors; the real contrast lies between the Six characters and the actors and not between the characters and the spectators. Finally, Moscarda in *Uno, nessuno e centomila* render us speechless with his disclosure: if I knew what you know that I know when you're saying to know... *ad infinitum*. Pirandello's novels show a remarkable ability to gainsay the world, to enrich the potential sources of insight into how human mind conceives the future by conversing with the *what if* propositions that the past has not abolished. As a result, there is not conclusion in the last sentence but a resonant perspective on the unlimited nature of this annular mental metric. Here one runs up to a seeming obviousness of the ring–shaped narrative structure. A ring has two sides that define two bordered yet clearly separated routes. If we were small Ulysses on this strange spherical world of a ring, we would find ourselves walking only on one surface, inside or outside the ring, and facing the Laestrygonians of our unilateral trip that, of course, will always lead back to Ithaca. Crossing the border is an unthinkable task for only fools, crazy or suicides to achieve, consequently the other side's point of view remains forever unknown. However, the half–twisted ring discovered independently and simultaneously, in 1858, by both August Ferdinand

Möbius (1790–1868) and Johann Benedict Listing (1808–1882) has only one side and only one edge. After crossing along the inside part one arrives to the exact opposite side of his starting point and only by continuing travelling till completing even a second round, one arrives to the actual beginning of his trip. Möbius topology is confusing and distressing for a human being used to think with the two–dimensional Euclidean instruments. The interactions in the three–dimensional world leave a large margin to the physics. But the interference of the fourth dimension gives interesting ground of analysis to narratology as well. Pointing on novels' framework, we observe that the main narrative characters experience a two–face and, therefore, twice–fertile voyage inside and outside the so–called system. Pirandello's novel protagonists search the limits of the conventional surrounding and provoke the rules of common logic till absurdity. Their sensation of alienation, their feeling of incomprehension and the vitality of their *hysteron* criticism to the others, are not random particularities of some awkward persons but a stable grade of awareness after a trip twice as long inside and outside the ordinary social topology. *L'esclusa* is literally excluded from the society and only after her experience on the external side of Möbius structure – without any emotional, financial and religious aid – she finally returned to her husband as before, but different. Silvia Roncella "[...] was dismayed to notice an irreparable separation from all her former life"[3] only after having concluded a trip away, in Piedmont, away from her life at Rome, to which she returned after all, firm on her decisions. Serafino Gubbio discovers the well berried sensibility by going back to the house of George's grandparents and to his own forgotten childhood and by leaving, at least for once, the professional alibi for his alienation found behind the cameras. (Pirandello 2005, chap. XV; Angelini 1990) And of course Mattia Pascal makes an emblematic travel from Miragno to Monte Carlo, challenging his fortune, his name and his entire existence. "My name is Mattia Pascal" is the first sentence of the novel; "My name is Adriano Meis" introduces himself the same person half way the Möbius trip and he finally returns to Miragno as Mattia Pascal, dead yet alive. The characters affront death, madness or social rejection during their journey because applying Möbius strip into narrative life is not an innocent task since it implicates a fifth and

[3] "[…] notava in sé con sgomento un distacco irreparabile da tutta la sua prima vita." (Pirandello 2005 I, p 724).

a sixth dimension: the human factor and the causality. The characters are confuting the society without crossing the boundary of its conventional norms but simply by exploring the second side of it: by giving recursive definitions of its principle in terms of itself. Finally, they return to the starting–point, that even if it is familiar to them it is always vigorous and unexpected, as there is no turning back to a simple *avvertimento del contrario* (*perception of the opposite*) when someone has experienced the humoristic *sentimento del contario* (*feeling of the opposite*). Proceeding from surface structure, that resides inside the narration under construction, into a deeper semantic structure, whereas the narration depends on its relations with a potentially infinite rank of our world, we find further interpretations for the way in which characters choose to roam. When they act on the outer cover of Möbius ring, they perceive the society differently from the way it perceives itself. "Chi ha capito il giuoco" (One has understood the game) (Pirandello 2006, p 1110) cannot be cheated anymore but he cannot even keep silent about the ill–defined sense of social correctness that he has detected. The characters reluctantly provoke by looking other's surprise when someone *in* the system jumps out and acts *on* the system as if it were *outside* the system (Hofstadter 1999). They themselves are taken by surprise too, because what they thought as a clear hierarchical system folds back in a self–violating way. The language itself becomes weird, it invents strange loops when it talks about itself, and thereby literature appeals to a valid meta–theory so as to prove once again its inconsistency. Gödel has already showed the irreparable errors in any axiomatic system with his proof of incompleteness theory, and has brought Epimenides paradoxes at the heart of mathematics. It's up to narratology now, certainly not to define an infinite – and thereby incomplete – system, but to adopt an overhead perspective and view the increasingly legible macrostructure. That means, in our case, that if we want to exploit Möbius circle as a projective image and not as a rhetorical device (as a metonymy or metaphor), we have to keep searching its dynamic rapport with fiction. A twisted route over the nonorientable surface of the narrative construction means that a person who travels within this surface finds paths that will reverse his handedness when he returns to the starting point. One travel around Möbius ring brings the person back to the point from where it all started, however with his view reversed. Only a second trip around would return him to his normal orientation. Pirandello's characters follow this path. They react in a different way, they are no longer silent, they even become violent, but they do not distinguish a precise moment in which they're changing perspective. The main character does not feel like shifting direction, although he is actually curving in a third dimension perpendicular to his two spatial dimensions. Finally, he returns to his family reversed: Would they notice the difference? Would he still hang out with the same persons, do the same job as he did and be the same husband as before? Nothing could ever guarantee such stability throughout an inverted standpoint. We still need to learn more about our universe before we determine the physical reactions when following nonorientable paths. This limitation opens new prospective to physics but in literature such ignorance employs a particular cluster of characteristics: revelation, attempt, hidden meaning, mystery, madness, surprise, otherness: the reader needs to collect such key–terms to awake to the sense of the new reality that is being narrated. In it, it’s normal that sensitive souls will react intensely at the vertiginous changes: emotions have been matured and the mind is now open to the air of freedom and of pure logic: here synonymous. That explains the protagonists’ obsession for mirrors, their outburst of laughter when they are on their own and the fit of insanity behind their locked doors. They are not capable to distinguish an object from its reflected image, so they make every possible experiment to test the limits of the narrative, yet real, unfinished suffering. It’s not their decision to discover the reversed side of the world. They were simply paying attention to the full, multiple context of their actions and, suddenly, a moment of epiphany beard them witnesses to a side–along passage of the traditional route that indicates an alternative of world’s falsehood, ongoing violence with the possible reclamation of its corruption. Once they have discovered it, they decide to perform a full second round even outside the ring. We have to excuse ourselves for abusing the terms inside and outside when Möbius strip has clearly abolished them. There is not inside or outside, but the torsion of the one into the other, the passage or the drift of the inside into the outside and vice versa. There is not a mere subjective or objective viewpoint or even one balanced between the two but a joint presence of subjectivity and objectivity that allows these factors to vary in their degree of revelation in the world as well as in the fiction. While looking at the world behind its mechanisms no one will stop from keeping observing the others from every possible angle. *Is this objectivity?* Maybe, or maybe it’s honesty, contemplation or otherwise madness. Whatever name we give to this cyclic movement, it is now obvious that it has to do with a very delicate movement. This perfect light motion has given some misleading interpretations about achrony in Pirandello’s novels (Patrizi 1996): it’s normal, because seen from a content–based point it can give the feeling of immovability and achrony: the same as the earth that gives the sensation of being steady despite of its perfect rotation. If we dive once again in the deep fundamental ground of the impression the leading characters have for the reversed world, a nausea is the smallest reaction in front of all the contrasts: inside and outside, the one and the others, appearance and essence, writing or living. Yet, it is amazing how characters keep going and conclude the route they have chosen without ever giving up, despite the difficulties, the rejections and the loneliness they feel. Committing suicide is an unknown solution in Pirandello's novels. When characters have enough narrative time at their disposal, they always postpone suicide, as they have already joined together with Nothing and All during life so that death couldn't offer them any truly new experience. We actually say nothing new, for physics already know that Möbius strip resists twice as long compared to the traditional belt when used as a driving belt: the load is better balanced on it, the consumption is smaller and, translated into fiction, one learns how to raise emotion to the level of intellect so as to equilibrate in him the burden of keeping on.

## 3 Conclusion

Literature does not represent a fictitious world; or rather literature is as fictitious as mathematics that keeps examining a two–dimensional world even if nothing in our world is flat. Applying Möbius ring in a narrative structure gives a rather quantifiable prospective in causality and in human awareness, even if there are still myriad of other dynamics that remain unexploited: in physics and in literature as well.

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# Confirming Special Relativity in Spite of Himself. The Origin of Ives–Stilwell Experiment

**Roberto Lalli**

**Abstract.** In 1938, the American industrial physicist Herbert E. Ives performed the Ives–Stilwell experiment, named after him and his assistant G. R. Stilwell. While physics textbooks describe the experiment as a confirmation of special relativity theory (SRT), Ives regarded the result of the experiment as a proof of the Larmor–Lorentz hypothesis of the contraction of the time–pulse of an atomic clock in motion through the ether. The aim of this communication is to provide a historical analysis of Ives's motivations to perform the experiment as well as of his theoretical presuppositions concerning the relationship between ether theories and relativity.

Key words: Special relativity theory, Einstein, Ether, Lorentz theory, Time–dilation factor, Fringe–mainstream relationships, Michelson–Morley, Kennedy–Thorndike

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## 1 A Short Introduction

The Ives–Stilwell experiment showed the existence of an optical effect that corresponded to the so–called transverse Doppler shift, namely a displacement of the spectral lines with respect to the classical optical Doppler effect that Albert Einstein (1879–1955) had derived in the framework of SRT in 1905. As such, textbooks usually quote it as an empirical support of SRT and certain scholars celebrated the experiment as the first direct confirmation of Einstein's dilation factor. In opposition, Herbert E. Ives (1882–1953) interpreted his own experiment as a proof of what he called the *Larmor–Lorentz theory* and never quoted SRT in his articles concerning the experiment (Ives and Stilwell 1938). Ives, indeed, never accepted the foundations of Einstein's theories and became the most authoritative opponent of relativity in United States between the late 1930s and the early 1950s. In spite of the relevance that certain physicists attribute to this experiment, scholars have given scant attention to its history. Elsewhere, I discuss at length Ives's overall anti–relativistic activity – his motivations, the influence of his background, the rhetoric he used, and the process of marginalization resulting from his heterodox views (Lalli 2013). In the present paper, I limit myself to elucidate Ives's theoretical approach to the Ives–Stilwell experiment. I invite the reader to integrate the contents of this paper with the background historian of science Arthur Miller (1981) provides on the role of the Ives–Stilwell experiment in the history of special relativity as well as with the description of Ives's ingenious experimental method in certain physics textbooks (French 1963).

## 2 Why Ives Conceived the Experiment

In the interwar period Ives was one of the most authoritative American industrial physicists, who had become the director of the electro–optical research department of the AT&T's Bell Telephone Laboratories since their foundation in 1925. Before 1937, Ives's main scientific activity was the study of the photoelectric effect for the developments of fax and television (Buckley and Darrow 1956). A change in the commercial policies of the Bell Labs allowed Ives to dedicate more time to his interests in the foundations of physics. From 1937 to 1953, Ives published more than thirty papers focused on relativity, whose aim was to expose what he perceived as the logical fallacies of relativity as well as to put forward an alternative theory based on the ontological existence of the stationary electromagnetic ether and absolute time. This long and productive research program started when Ives published arguments on the need to perform an experiment on the second order Doppler effect (Ives 1937a, 1937b, 1937c, 1937d). In these papers, Ives did not mention SRT and referred only to what he called the *Larmor–Lorentz theory*. Put simply, what Ives meant for Larmor–Lorentz theory was a theory that prescribed well–defined modifications of rod–lengths and clock–rates depending on the motion of rods and clocks through the stationary ether. According to Ives, the stationary ether constituted an absolute rest frame in which lengths and time had an absolute meaning. If an object moved through the ether with a velocity *v,* his longitudinal dimension would physically change according to the Fitzgerald–Lorentz contraction formula. Namely, the relationship between the longitudinal length of the body in motion and that of the stationary one would be:

$$L' = \left(1 - \beta^2\right)^{\frac{1}{2}} L \tag{1}$$

where $L'$ is the longitudinal length of the body in motion; $L$ is the longitudinal length of the body at rest in the ether; and $\beta$ is $v/c$; namely, the ratio between the velocity of the object in the ether and the velocity of light in the ether. As for the change of clock–rates of a clock in in motion through the ether, the value corresponded to what Ives called the *Larmor–Lorentz frequency change*. Namely, the frequency of a clock in motion through the ether would change according to the formula:

$$\nu' = \left(1 - \beta^2\right)^{\frac{1}{2}} \nu \tag{2}$$

where $\nu'$ is the frequency of the clock in motion through the ether; and $\nu$ is the frequency of the clock at rest in the ether. Ives christened the set of Eqs. 1 and 2 the *Fitzgerald–Larmor–Lorentz contractions*, and conceived the Ives–Stilwell experiment in order to test their validity. Ives's *Larmor–Lorentz theory* corresponds to the last version of Lorentz's theory, which was included in the treatise *Theory of Electron*s (Lorentz 1909).[1] Commentators agree that if one limited oneself to optical experiments that deal with patterns of light and darkness, the empirical consequences of Einstein's SRT and Lorentz's 1909 theory would be identical. Therefore, a test of the Eqs. 1 and 2 corresponded to a test of SRT and Ives's private correspondence shows that he was aware of this equivalence. In other words, Ives was proposing an experiment that, implicitly, could disprove or confirm one of the main empirical consequences of SRT.

Ives considered the experiment on the second order Doppler effect as a crucial test to determine a factor in the formulas of the change of rod–lengths and clock–rates, which previous optical experiments had left unsettled. Ives argued that the Michelson–Morley experiment and the Kennedy–Thorndike experiment had demonstrated that rigid rods and clock–rates changed based on their motion through the ether. The set of these experiments, Ives stated, was usually interpreted as a definitive proof of the validity of the Eqs. 1 and 2 – the Fitzgerald–Larmor–Lorentz contractions. Historically, the Michelson–Morley experiment was interpreted as a direct proof of the validity of the Fitzgerald–Lorentz contraction, while the Kennedy–Thorndike experiment was considered to be a demonstration of the relativistic dilation of time or, in Ives's terminology, of the Larmor–Lorentz frequency change. Ives, however, argued that the two experiments did not unequivocally establish the validity of such contractions. Roy Kennedy and Edward Thorndike (1932), indeed, interpreted the null result of their experiment as a confirmation of the time dilation formula only because they assumed that the Michelson–Morley experiment had previously proved the validity of the Fitzgerald–Lorentz contraction. It was possible, however, to explain the null result of the Michelson–Morley experiment by assuming that the arm–lengths of the Michelson interferometer changed in a different way. If one assumed the existence of the stationary ether and the constancy of the velocity of light *c* in the ether, the null result of the Michelson–Morley experiment would

[1] The historiographical literature presents a number of different interpretations of Lorentz's theory as well as of the distinctions between Einstein's SRT and the various versions of Lorentz's theory. It is not possible to evaluate here the different historiographical positions. In my comparison between Ives's earlier theory and Lorentz's various theories I will take for granted only what all commentators agree about.

only prescribe that the lengths of the two perpendicular arms of an interferometer moving in the ether changed according to the well–defined relation:

$$L_L = \left(1-\beta^2\right)^{\frac{1}{2}} L_T \tag{3}$$

where $L_L$ is the length of the arm parallel to the motion of the interferometer in the ether and $L_T$ is the length of the arm perpendicular to such a motion. As Eq. 3 shows, the Fitzgerald–Lorentz contraction is just one of the various possibilities and depends on the choice $L_T = L$; namely, by assuming that the length of the arm perpendicular to the direction of motion remained unaffected. According to Ives, then, previous optical experiments left a factor that was not unequivocally established. The Michelson–Morley experiment and the Kennedy–Thorndike experiment, Ives stated, prescribed only the validity of the relations:

$$\left\{ \begin{array}{l} L_L = \left[\left(1-\beta^2\right)^{\frac{1}{2}}\right]^{n+1} L \\ L_T = \left[\left(1-\beta^2\right)^{\frac{1}{2}}\right]^{n} L \\ v' = \left[\left(1-\beta^2\right)^{\frac{1}{2}}\right]^{1-n} v \end{array} \right\} \tag{4}$$

The indeterminacy of the factor *n* in Eq. 4 implied that the null result of both the experiments might be explained by any choice of *n,* the Fitzgerald–Larmor–Lorentz contractions corresponding to the choice *n*=0. According to Ives, his predecessors George F. Fitzgerald (1851–1901), Joseph Larmor (1857–1942), and Hendrik A. Lorentz (1853–1928) chose the value *n*=0 to explain the result of the Michelson–Morley experiment by following lines of reasoning that did not depend on the famous experiment itself. Ives did not address the reason why such scientists indicated the longitudinal contraction as the only effect that could explain the Michelson–Morley effect. Contemporary historiography has convincingly argued that Fitzgerald, Larmor and Lorentz were all developing Maxwell electromagnetic theory in order to apply it to bodies in motion. By pursuing such a research program, they reasonably extended the behaviour of the electrostatic field to intermolecular forces (Hunt 1969; Warwick 1992; Darrigol 1994). Ives could avoid explaining the reasons why the three scientists did not consider alternatives because he followed a completely different approach – based on inductive reasoning from the result of optical experiments – and did not address any issue concerning the behaviour of the electron and of the electromagnetic field. This constraint allowed him to show that a third optical experiment was necessary in order to evaluate the factor $n$ in Eq. 4. Ives argued that a test on the fringe–shift due to the second order Doppler effect was the crucial experiment to prove the validity of the Fitzgerald–Larmor–Lorentz contractions and, implicitly, of SRT. In 1938, Ives published the result of the experiment he had performed with the support of his technical assistant at Bell Labs. The observed fringe–shifts of hydrogen ions in motion in a canal–ray tube were in perfect agreement with what Ives had calculated by assuming the validity of the Fitzgerald–Larmor–Lorentz contractions. Just one year later, most physicists began regarding the experiment as a confirmation of SRT, and in 1949 the relativist cosmologist Howard P. Robertson (1903–1961) confirmed Ives's own statements about the relevance of the experiment. Robertson (1949) argued that, within the limit of the inductive method, the Ives–Stilwell experiment, along with the Michelson–Morley and the Kennedy–Thorndike experiments, constitutes a complete empirical foundation of SRT.

## 3 Conclusion

The history of the Ives–Stilwell experiment is interesting because it highlights various aspects of the complex way fringe scientists interact with the mainstream in the production of certified knowledge. In his private letters, Ives clearly exposed his distaste for the logical foundations of relativity and for its impact on the notions of space and time. On the other hand, he contributed significantly to the empirical confirmation of the theory he wanted to challenge. The complexity of the fringe–mainstream relation only increases when one tries to understand Ives's hidden motivations. There is no evidence that Ives hoped that his experiment would have disproved SRT. Quite the contrary, Ives never seemed to doubt the validity of relativistic formulas, although he provided a completely different interpretation. Archival documents confirm that Ives really believed that the Ives–Stilwell experiment was extremely important to validate the formulas on which he was basing his own ether theory, which was a development of the theories of Lorentz and Larmor. The interaction between fringe and mainstream in the production of scientific knowledge finds no place in the various epistemological efforts to construct a rational methodology of science. Ives's case suggests that activities made far from scientific orthodoxy might actually influence mainstream research in unpredictable ways. Robertson accepted Ives's demonstration that the Lorentz transformations were not unequivocally determined by previous optical experiments. Implicitly, Robertson was recognizing that American textbooks were disseminating a distorted image of the empirical foundation of SRT, which was often depicted as an inductive extrapolation from the Michelson–Morley experiment. Although Ives's overall approach lacked generality and failed to attract his peers' interest, the potential value of his criticisms sparked certain scientific debates that eventually led to a clarification of the logical foundations of SRT.

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# Gerald James Whitrow's Philosophical Approach to the Expanding Universe

**Giovanni Macchia**

**Abstract**. One of the few authors to have explicitly connected the cosmological issue of the universe's expansion with the philosophy of space is Gerald James Whitrow (1912–2000). A man of extraordinary erudition, he was a British physical mathematician, cosmologist and historian of science. His main contributions were in cosmology and astrophysics, but he also wrote noteworthy essays in history and philosophy of science, above all on the concept of time. His masterpiece is *The Natural Philosophy of Time*, a monumental book published in 1961 and 1980. My analysis will be focused on it, specifically upon his position on the philosophical implications regarding space as they emerge from modern cosmology.

Key words: Whitrow, Cosmology, Expanding universe, Philosophy of space

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## 1 Intrinsic Versus Extrinsic View of the Universe's Expansion

Whitrow philosophically examines the topic of the expanding universe in the sect. 6.4 of the 2nd ed. of *The Natural Philosophy of Time*.[1] He begins this section, concerning the relation between cosmic time and expanding universe, saying: "Basically, two different types of relation may be envisaged between matter as a whole and space, depending on whether we adopt the 'relational' or the 'absolute' theory of space" (Whitrow 1980, p 288). According to the former theory, usually associated to Leibniz (1646–1716) but in reality much older, "space is the nexus of spatial relationships of material objects", whereas for the latter, usually associated with Newton (1642–1727), space is "intrinsically distinct from matter" and exists in its own right and is therefore absolute (Whitrow 1980, p 288). Later on, he introduces the different ways by which the universe's expansion could be considered by the supporters of these theories:

> According to the 'absolute' theory, such expansion would be an expansion of the material universe into outer empty space, like the diffusion of a gas into a surrounding vacuum. According to the 'relational' theory, there is nothing – not even empty space – outside the universe and its expansion is simply a change in the scale relationship of the universe as a whole to the linear dimensions of typical constituents: for example, the diameter of a typical atom, the radius of an electron or proton, or the wavelength of a photon emitted in a specific atomic transition.[2]

Thus, according to Whitrow, expansion should be considered *extrinsically*, i.e. with reference to an outer empty space in which it is embedded, in order to discriminate between the two theories. An early criticism regards exactly this extrinsic approach. The point is that, mathematically speaking, an external pre–existing space is not mandatory at all. The curvature is a property that may or may not be conceived as belonging to a space

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[1] I will quote only the 2nd ed., but the parts in which I am interested here are practically identical in the 1st ed. as well (§ V.4). In order to better elucidate Whitrow's view, I also examined all his books and most of his papers, unfortunately without finding any comments related to the philosophy of space.

[2] Whitrow 1980, p 290.

embedded in a larger space. In general, curvature is *extrinsic* if it is owned by an object in relation to a higher–dimensional space that contains it, and such a curvature is determinable only by confronting the object's elements in relation to the space–container's elements. Instead, curvature is *intrinsic* if it is determinable using only operations performed on the elements of the object itself. Therefore, a space of any dimension can be intrinsically curved in the sense that curvature is a property defined at every point of that space rather than defined with respect to a higher–dimensional ambient space. Obviously, the ontological status of the additional dimensions involved in this distinction is an issue completely separate from the mathematics. And we do not know nothing about the existence of these higher dimensional spaces. We just know that General Relativity works intrinsically: it proposes that gravity actually results from an intrinsic curvature of spacetime.

Universe's expansion can be considered with these two approaches, too. Similarly, we do not know if our universe is expanding in a higher dimension space or in *literally* nothing. However, I think that – if one prefers to adopt an ontology deriving, as far as possible, from our best physical theories, and in the meantime opting for a kind of ontological parsimony – the better choice is simply regarding the expansion as a sort of spatially auto–contained phenomenon intrinsic to the universe itself.

Hence, contrary to Whitrow's remarks, the existence of some bigger containing space is not a necessary prerequisite. In all probability, Whitrow's stance is influenced by an old–fashioned strict Newtonian view about space, according to which space is an infinite immutable all–embracing container that does not participate in material affairs, namely space is completely detached from the expansion of its matter contents. However, also in such a case, recalling that the term *universe* defines that unique all–comprehending entity which necessarily must include space itself, it is still possible to keep an intrinsic approach to the expansion without any detriment to absolutism or to relationism by simply focusing on the ontological status of the inner space to the universe itself.

The fact that Whitrow does not contemplate the intrinsic approach is a little bit strange. Surely, when considering his main contributions to science, he belongs to the first half of the last century rather than to the second one, so his approach to some scientific issues could sometimes feel the effects, in terms of both "updated" knowledge and mentality, of this more distant provenance. However, this intrinsic approach to the universe is not recent at all.[3]

## 2 Mathematical Techniques and Philosophies of Space

Whitrow's analysis goes on with the following considerations stating an association between the two mathematical techniques – as he calls them – usually adopted to describe the expansion of the universe, and the two previously mentioned philosophies of space:

> Since the idea of world expansion was first suggested, two different mathematical techniques have been invented for the construction of world models: the technique of an *expanding space* and the *kinematic technique*. It has been customary to regard these merely as two different mathematical methods, and indeed it has been shown that there exists a close relationship between them. Nevertheless, there is a vital philosophical difference, for the expanding–space technique is the natural concomitant of the relational concept of space, whereas the kinematic technique is most naturally associated with the idea of absolute space. Thus, in the one case there is motion *of* space and in the other motion *in* space, i.e. in the former space is the framework of all matter and this framework expands, whereas in the latter attention is concentrated on the type of motion of the fundamental particles [footnote: "Idealizations of the principal aggregates of matter (clusters of galaxies)"] rather than the space structure.[4]

Thus Whitrow proposes these relationships: the technique of expanding space is to be coupled to the relationist view of space (in this case, he specifies, there is motion *of* space), whereas the kinematic technique is to be related to the absolutist view (in this case there is motion *in* space).

I think that these associations are not shareable for at least two reasons.

The first one is that those mathematical techniques are not different only because they may be assigned to two philosophical views, as Whitrow affirms, but because they are deduced from two *physical* phenomena. The common ground is the increasing wavelength measured in the radiation

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[3] For example, the great cosmologist Robertson (1949, p 317) sustained it.

[4] Infeld and Schild 1945, p 290.

coming from the galaxies. This increase can have the nature of a Doppler redshift or a cosmological redshift. Although both are proof of an increasing distance between the galaxies and us observers, they are the results of two different physical phenomena that, according to modern cosmology, occur at different spatial scales in our universe.

When we talk about the expanding universe, we refer to those large–scales pertaining to dimensions at least as big as a cluster of galaxies. In this context, Cosmological Principle holds, so it is only the cosmological redshift, as derived from the so–called *Friedmann–Lemaître–Robertson–Walker metric* (in turn obtained from the Cosmological Principle), that must be taken into account. This redshift is interpreted as the effect of an expanding metric. In other words, the mutual recession of the clusters, expressed by the locution *expanding universe*, is a physical phenomenon explained in terms of another physical phenomenon usually labelled as *expansion of space*. This is very roughly the standard cosmological view.

The Doppler redshift, on the contrary, is an interpretation of the measured spectral shifts consistent only with a small–scale phenomenon, namely the recession of celestial bodies in bound systems detached from the large–scale expansion. So the Doppler shift is explained as due to the relative motions *in* space between the emitting source and the receiver. This is the kinematic approach to expansion, typical of Milne's cosmology (a model worked out by Milne (1896–1950) in which there are *effective* motions of the fundamental particles in a non–expanding flat spacetime).[5] For this reason, I think there is something more than a (though important) philosophical difference – as Whitrow believes – between those mathematical approaches: there is something physical, which implies different mathematical techniques and, in the meantime, allows us to discriminate between two philosophical pictures.

The second and most important reason of my disagreement with Whitrow concerns the association between the mathematical techniques and the philosophies of space. In my opinion his association should be inverted: the expanding–space concept would reveal an absolutist

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[5] Significantly, Whitrow speaks exclusively of Doppler shifts. Just in one case (Whitrow 1980, p 296) he writes the formula of the cosmological redshift, but he does not attach any importance to it, neither in terms of the physical phenomenon underlying it, nor in terms of its possible philosophical consequences.

metaphysics, whereas the kinematic approach most naturally might be associated with a relationist position.

In relation to the expanding–space technique, I do not understand why it would sustain a relational concept of space according to which, as Whitrow himself says, "there is no independent spatial background against which systematic changes in the geometrical structure of the universe occur" (Whitrow 1980, p 294). The point is that it is exactly *that* spatial background which, according to this technique, changes *independently* of the matter contents.[6] I wonder how it is possible to avoid the next deduction: *if there is motion of space* or *space is the framework of all matter and this framework expands* – as he writes – then such attributions of motion or of expansion necessarily result in an ontological commitment to space itself. And, it goes without saying that such a commitment to the existence of space would be contrary to any relationist standpoint. Furthermore, if Whitrow regards this framework only as a mathematical tool, on which bases does he then explain the differences between absolute and relational views? Maybe only by adopting that unsatisfactory extrinsic approach seen before.

With regards to the second of Whitrow's associations, I think that the kinematic technique may be associated, as he claims, with an absolutist conception of space. It is true that if our attention is concentrated – to use his words – on the type of motion of the fundamental particles, then we can regard their motions as occurring in an absolute space *à la* Newton. Nonetheless, are we sure that in the kinematic technique an ontological commitment to an absolute space is regarded as necessary? I do not think so. If our attention is concentrated *on the fundamental particles alone*, namely, on the trivial fact of their existence, what results is simply the necessity to associate the kinematic technique to a relationist position

[6] Actually, this independence is controversial. Expanding space could also be an *emergent* phenomenon closely tied up with clusters recession. I am, however, inclined to think that expanding space may assume a sort of ontological priority (thus, an independence) on ordinary matter, if one thinks to the fact that General Relativity also contemplates de Sitter's *empty* (although with a non-null cosmological constant) but still expanding universes. Again, things are not so simple: the energy expressed by the cosmological constant, put on the side of the matter-energy contents, would break that independence, rendering space structure supervenient on that energy. However, such a controversy does not prejudice my criticism of Whitrow.

# The Count Paolo Ballada de Saint Robert and his *Receding of the Glaciers*

**Federica Maffioli and Gianfranco Medici**

**Abstract.** The Count Paolo Ballada de Saint Robert (1815–1888) was an Italian scientist mainly busy in mechanics and thermodynamics. This paper describes the conclusions of Saint Robert concerning the retreat of glaciers and tries to explain his theory through modern knowledge.

Key words: Adhémar, Alps, History of climate change, Glaciers, Marsh, Milankovitch

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# 1 A Short Introduction

An increase of scientific studies on glaciers started only in the middle of XIX$^{th}$ century. The interest was great and for the Italian Alps of Piedmont were involved scientists, geologists and glaciers scholars. In Italy the scientific approach to the glaciers observation was driven by the rise of Italian alpinism where many of these scholars belonged (Malaroda 1995). In 1927 Federico Sacco (1864–1948), President of the Committee of Glaciology, collected and ordered all the main glaciology studies, where next to important scholars it's mentioned the note of Saint Robert[1] defined as a *bearer of good observations on glaciology* (Sacco 1927). In 1930 the Saint Robert's note was listed in the bibliography of the Bulletin of the Italian Glaciological Committee that brings together all the major scientific studies on glaciers (Capello 1930).

[1] The count Paolo Ballada di Saint Robert was born in Verzuolo, Italy on the 10$^{th}$ June 1815. For biographical sketch see Pisano 2013 (and, Medici and Maffioli in this book). He was a member of the *Reale Accademia delle Scienze* of Turin, the *Reale Accademia dei Lincei* of Rome and of the *Società (Academy) Italiana called XL* (forty). His life was dedicated to technical-scientific studies: Ballistics, Artillery, Mechanic, Hypsometry, Thermodynamic and natural studies. His studies of Thermodynamic was very important: he was the first in Italy to write about Sadi Carnot and his work *Principes de Thermodynamique* (1865 et editions) was adopted as text book in the most important Universities in Europe. Raffaele Pisano describes Saint Robert as an important promoter of scientific culture, scholar of military technology among the most distinguished of his time, he succeeded in combining pure and applied science, art and social interests into one of the most elevated synthesis (Pisano 2013; Gillispie and Pisano 2013; Pisano 2007). As a passionate mountaineer, he did many alpine excursions and he was the main promoter and organizer of the first Italian ascent to mount Monviso in 1863 with his friend Quintino Sella, and contributed to the foundation of the Italian Alpine Club in the same year; he was also Honorary Member of the *Alpine Club of London* and intimate friend with William Mathews, John Ball and Francis Fox Tuckett. He retired in Castagnole delle Lanze in 1878 until 1884. He died in Turin in 1888.

## 2 Why Saint Robert Wrote this Note

In the paper presented at the Royal Academy of Lincei on 2nd December 1883, published also in the Alpine Journal[2], Saint Robert submitted observations to the Note entitled *On the temperature corresponding to the glacial period* (Blaserna 1883–1884a, 1883–1884b, 1882–1883) presented by Pietro Blaserna (1836–1918). In a letter[3], dated 20 November 1883, Saint Robert manifested to his friend Quintino Sella (1827–1884), President of the Royal Academy of Lincei of Rome, the intention to submit a paper about glaciers to integrate the theories exposed by professor Blaserna. This caused some discontent in Blaserna who soon answered in two papers published at the Royal Academy of Lincei (*Ivi*). It didn't follow an official response from Saint Robert probably because he was already sick and tired. The interest of Saint Robert for a subject far to his expertise is due to his work as scientist mountaineer who led him directly to practice and study glaciers. For example, during the ascent to Mount Ciamarella he wrote: "Being the technical alpine language yet to be formed, I make bold to propose the word *rima* to indicate the cracks formed in glaciers, to which the french people give the name *crevasses* [...]" (Saint Robert 1867, p 247). It's probable that Saint Robert, in the formulation of his theory, was influenced by George Perkins Marsh (1801–1882), U.S.A. ambassador in Turin in the early years of Kingdom of Italy and *ante litteram* ecologist, author of the book "Man and nature" translated also into Italian[4] (Perkins Marsh 1870).

### 2.1 Blaserna's Theory

In extreme synthesis: Pietro Blaserna, through his mathematical studies and the collection and processing of weather data, concluded that the maximum development of european glaciers corresponded to a temperature higher than current one (Blaserna 1882) and agreeing with the theories of Auguste Arthur de la Rive (1801–1873), John Tyndall (1820–

[2] Alpine Journal, n. 85, vol. XII, August 1884, pp. 134–136.

[3] Fondo Carte Quintino Sella, letter n. 885, Sella Foundation, Biella.

[4] We know for sure that this book was part of his personal library, as found in the list of Saint Robert's books donated to Biblioteca Civica di Torino.

1893) and Antonio Stoppani (1824–1891), he said that the temperature of Europe during the Ice Age was higher than current (De Marchi 1911).

## 2.2 Saint Robert's Theory

In the first observation to Blaserna's theory, Saint Robert indicates that Blaserna does not consider the decrease of temperature to explain ice age (Saint Robert 1883–1884). Saint Robert points out that there are evident traces of glaciers in places where currently there are no more, as for example to the Gran Sasso of Italy. It is impossible, as Blaserna instead supposed, that the increase of temperature could make possible the return of these glaciers, because in this conditions the perennial snowline rises and the condensing surface disappears. The traces of past glaciers show that, in the ice age, the perennial snowline was much lower than actual and this was possible only thanks to a lower temperature or at least to a lower summer temperature. Saint Robert concludes that atmospheric temperature was lower in the ice age and not higher, as Blaserna supposed.

The second observation it's about the significant retreat of glaciers during the XIX$^{th}$ century. According to the theory of prof. Blaserna such receding corresponded to a decrease in temperature. Saint Robert explains how, not only the average annual temperature has not changed much in recent years, but remains mostly constant from 33 centuries. *What is the mistake of Blaserna's theory?*

Saint Robert says that Blaserna did not consider the ablation of a glacier. When the extension of a glacier is constant, annual ablation is exactly equal to the amount of snow falling at the top every year. A glacier, increases or decreases from one year to another depending on whether the ablation is less than or greater than the amount of snow fall. But what is the cause of receding of glaciers? Saint Robert says that the main cause is the progressive decrease of precipitation during the cold season and the increase of summer temperature. The condensed water vapour at the top during the hot season, does not contributes to the formation of glaciers. The water vapour condensed during the cold season remains on the mountains in a state of snow and feeds the glaciers. At the same time, higher summer temperatures contribute to glacier retreat, increasing the ablation's erosion work. The weather observations in Turin, Geneva, Paris and San Bernardo, show, compared to 50/60 years earlier, a significant decrease in rainfall during the cold season and an increase of summer temperatures. These two conditions were caused, as Saint Robert says, by continuous deforestation of mountains and plains, and by the drainage works of rivers, marshes and ponds. All these actions, operated by man, reduced the evaporating surface and the important water vapour effect on mitigating summer temperatures and winter solar irradiation.

The theory of Saint Robert, to explain the Ice Age, is that in prehistoric period the evaporating surface was greater than the current. As a consequence, the huge quantity of atmospheric water vapour reduced the temperature difference between the cold and the hot season, lowering the level of perennial snow. During the Ice Age the temperature of Europe, or at least the summer temperature, was lower than the current and that the cause of the receding of glaciers is not attributed to astronomical causes, as some scholars believed at that time, but simply caused by climate change, in part caused by human activities on the earth's surface.

## 2.3 Saint Robert's Theory Today

Luca Mercalli, contemporary glaciologist, climatologist and meteorologist, supports that Saint Robert is certainly more acute than Blaserna when he excludes categorically that a glaciation can be the result of an increase of temperature, identifying correctly glacial conditions as the result of a decrease of temperature (today we know 6–10°C lower than the current). It's absolutely correct the interpretation of the glacial dynamics (today we call it *mass balance*) that is the balance between incoming snowfall on the glacier and ablation of ice during the summer. Saint Robert incurs, however, in a series of inevitable mistakes due to the lack of systematic studies and of a complete database that would have allowed him a correct analysis. He makes a mistake when he doesn't consider the astronomical causes for the decrease of temperature. Joseph Alphonse Adhémar (1797–1862), an eminent French mathematician, was the first to propose in 1842 a rigorous scheme of astronomical forces that control the Earth's orbit and the glacial cycles. Adhémar theory was implemented in 1875 by James Croll (1821–1890). In the theory, still relevant today, exposed in 1941 by Milutin Milankovitch (1879–1958) it's demonstrated how some orbital parameters, as for example the eccentricity of Earth's orbit around the sun, the tilt of the Earth and the procession of equinoxes change periodically, influencing the amount of incoming solar radiation on Earth and therefore changing the climate. Saint Robert's theory also does not consider the general atmospheric circulation and its synoptic variations to explain the decrease of winter precipitation. The cause of this decrease isn't due to local deforestation (as suggested by Saint Robert) because the true evaporating surface is not local, but rather represented by the Atlantic Ocean and the Mediterranean Sea. Saint Robert didn't have enough data to identify the mechanisms that lead European and alpine climatology and that control the advection of moisture in the Alps. The provisions of the atmospheric currents, on hemispheric scale, govern the alpine rainfall/snowfall by random or cyclic fluctuations, linked to oceanic currents or to changing in atmospheric pressure. Human activity was also a negligible cause on the climate change, because during XIX$^{th}$ century the global population was only 2 billions (while today is 7 billions) and the use of fossil fuels was limited. The only consequences of deforestation operated by man, was hydrogeological instability in mountain regions. The retreat of glaciers, observed at the end of 1800 is not due to human activities but to the end of the Little Ice Age (1300–1850), caused both by a partial decrease in solar activity (Maunder's Minimum) and to a particular frequency of volcanic explosions that projected into the atmosphere large quantities of dust, decreasing solar radiation, temperature and increasing precipitations (Mercalli 2009).

## 3 Conclusion

It's important to remember that the Italian Glaciological Committee (the first scientific approach to glaciology in Italy) was founded in 1895 twelve years later than Saint Robert's theory. The Count tried, with more than a century in advance and despite the limited knowledge of its historical period, to outline problems that would have prevailed only in more recent times. We think that it is useful to propose this note to better understand the scientific approach, the intellectual honesty and promotion of scientific culture of this great character, mostly forgotten in the history's folds.

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# Ptolemaic and Copernican Globes in the 17th Century: short Remarks on the Handbooks by Blaeu and Bion

**Flavia Marcacci**

**Abstract.** The famous Dutch cartographer and publisher Willem Janszoon Blaeu (1571–1638) qualified himself as an instrument and globe maker under direction of Tÿcho Brahe (1546–1572). In his *Institution astronomique* Blaeu explained the differences between techniques of construction and usage of Ptolemaic and Copernican globes. Nicolas Bion (1652?–1733) was a less renowned globe maker. In *L'usage des globes celestes et terrestres* he described how constructing Ptolemaic and Copernican globes. An interesting and unusual proof of persistent problem of world systems comparison in XVII$^{th}$ century.

Key words: Ptolemaic globes, Copernican globes, Astronomy, Blaeu, Bion

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## 1 The Solarium, Tellurium and World Systems

The history of scientific instruments is also a history of science, and this is really true in the case of some particular instruments of XVII$^{th}$ century as terrestrial and celestial globes. The fascinating and significant role of them in history of culture of this period is big (Dekker 2004; Dekker 2007) and the terrestrial and celestial globes have a curious role since the craftsmen try to adapt them to different proposed world systems in that time. The terminology can show this debate, too: a globe is called *solarium* when it is used in a Ptolemaic way to demonstrate the Sun's movement and it is appealed *Copernican*, when its movements represent the motion of the Earth (Dekker 1996, p 547).[1] Thus these instruments are precious to understand how people, outside the community of the scholars, could understand the geometrical structure of the world, particularly the craftsmen who make these models concrete. The globes' production at the turning of XVII$^{th}$ century moves from Holland to Italy, France and England (Schmidt 1999, p 245): especially celestial globes have a role in divulging the Copernican notions and deciding which world system is correct.

## 2 Blaeu's Handbook for Celestial Globes

Martinus Hortensius (1605–1639), professor of Mathematics in Amsterdam and contemporary with the famous cartographer and globemaker Willem Janszoon Blaeu (1571–1638), in the preface of *Institution astronomique de l'usage des globes et sphères célestes et terrestres*, praises the book for its skill to explain the Copernican system and to compensate the obscurity of the Copernican text (See Blaeu 1642, [18] folio B3*r*). After a century John Keill (1671–1721) will repeat the same opinion in the *Essai sur l'Histoire de l'Astronomie Moderne* at the beginning of his *Institutiones astronomiques* (Keill 1746, p xxv).

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[1] Another kind of terrestrial globe is the English globe, a static model of Earth of which ones of the differences with other globes are that the fixed horizon ring and the hour circle of the common globe are directly engraved on the globe gores (Cfr. Dekker 1996, pp 547–548).

Blaeu works with Tÿcho Brahe for two years (1595–96) at observatory of Hven (Denmark). When he returns to Amsterdam he starts working as cartographer and mapmaker. Here, he becomes so successful to be appointed in 1633 as *Map Maker* of the Republic of the Estates General of Amsterdam (Stevenson 1921, pp 19–22). For his celestial globes he could have used some observational data that Tÿcho has given before publication. As Stevenson supposes, Blaeu's calculations and works were useful for Kepler (Stevenson 1921, p 20). In his *Preface* at *Institution astronomique de l'usage des globes et sphères célestes et terrestres* Blaeu presents his book: the first part is about the construction of Ptolemaic globes; the second part is about the Copernican globes which aren't in commerce. He knows the first part is not original at all and he affirms clearly the superiority of Copernican system in order of its beauty and harmony. In spite of this, the Ptolemaic part takes up two thirds of the volume: the resolution of a lot of problems values also for the Copernican relative ones. For this reason the instructions about the use of globes in navigation are treated only in the Ptolemaic part (Blaeu 1642, p 177).
Everyone of the two parts of the volume is divided in two books: the first one about the theory, and the second one about the instructions for making globes:

**Table 1** The Structure of the Blaeu's Treatise[2]

| Premiere partie: *Suivant l'Hypothèse de Ptolémée qui veut que la Terre soit immobile* | Seconde partie: *Suivant la vraye Hypothèse du monde de N. Copernicus qui pose que la terre est mobile* |
|---|---|
| Livre I *De la composition et parties des globes* | Livre I *De la Fabrique & division de sphères* |
| Chap. 1 *Des Cercles qui son tau de hors des Globes, & sont communs à l'un & à l'autre* | Chap. 1 *De l'ordre des Sphères célestas* |
| Chap. 2 *Des Cercles du Globe céleste* | Chap. 2 *De la construction de Sphères, & de leur comparaison avec le ciel* |

[2] Sometimes the word used for titles or sections are little different, although the same meaning.

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|---|---|
| Chap. 3 *Des Cercles du Globe terrestre* | Chap. 3 *Du triple mouvement de la terre* |
| Chap. 4 *De la diverse division des pays* | Chap. 4 *Enseigne à trouver par la Sphère le triple mouvement de la terre* |
| Chap. 5 *Des étoiles, & de leurs différences, nom, & division* | Chap. 5 *Enseigne la construction de la Sphère particulière des étoiles fixes & du Globe de la terre* |
| Chap. 6 *Du mouvement de la Sphère des étoiles fixes, à l'entour de l'Aißieu*[3] *du Zodiaque* | |
| Chap. 7 *Du mouvement du Soleil en l'Ecliptique* | |
| Chap. 8 *De l'Horizon* | |
| Livre II | Livre II |
| *De l'usage des globes* | *De l'usage des sphères* |
| Section 1: *du lever & coucher des corps célestes, & des autres choses qui concernent ceste matière* | Première partie: *Du lever & coucher des corps célestas, & des autres choses, qui s'y rapportent* |
| 53 problèmes | 52 problèmes |
| Section 2: *Des quadrants au Soleil* | Second partie: *Des quadrans Solaires* |
| 17 problèmes (LIV–LXXI) | 16 problèmes (LIII–LXVIII) |
| Section 3: *Des Rombes & de leur usage en la Navigation* | |
| 9 problèmes (LXXII–LXXIX) | |

In the Chapter III Blaeu introduces some theoretical lines to understand how the Earth can move with three kind of motion:

> The first movement, that carries out on itself, is the daily motion, that is fulfilled around its axis from West to East during a time of 24 hours, and that causes the daytime and the night-time. The second movement is the annual movement of the centre of the Earth around the Sun, from West to East too, following the sequence of the signs, that has given between the spheres of Venus and Mars, and that travels the circle of 12 signs of the Zodiac. This is the movement that causes the appearance of solar motion through the Zodiac... The third movement, that completed itself in a little less than one year, carries out on itself, on the contrary to this movement

[3] It stands for "assieu".

> of the centre of the Earth and the succession of the signs, around a parallel line to the axis of the Ecliptic; from the East to the West.[4]

Some examples explain the movements of Earth, sometimes not very complete but always with a clear style. For examples, about the 3$^{th}$ motion Blaeu remains rather generic, without explaining fully the variation of the inclination of the terrestrial axis to justify the change of the seasons and admitting only the parallel motion of terrestrial axis.

## 3 Bion's Handbook for Celestial Globes: a brief Comparison

Nicolas Bion (1652–1733) is a French mathematician and maker of globes and scientific instruments, *Ingénieur du Roi pour les instruments des mathematique* and since 1681 he has an *atelier* on the Quai de l'Horloge (Bion 1703, pp 332–333). In the *Préface* of his more popular book *L'Usage des globes célestes et terrestres, et des sphères, suivant les différents systèmes du monde* (Paris 1699),[5] Bion claims that observations and documents of the Academie Royale de Sciences are the base of his work. Initially he explains different world–systems in the *Traité de*

[4] "Le premier, qui se fait en soi–meme, est le journalier, lequel s'accomplit à l'entour de son proper aissieu d'Occident en Orient en l'espace de 24 heures, & cause le jour & la nuict […]. Le second est le susdit movement annuel du centre de la terre autuor du soleil, d'Occident aussi en Orient, suivant la succession des signes, le quell se fait entre les Spheres de Venus & de Mars, & descript le cercle des 12 signes du Zodiaque. Ce movement est cause qu'il semble que le Soleil se mouve ainsi lui mesme par le Zodiaque… Le troisiéme mouvement qui s'acheve en un peu moindre espace que d'un an, se fait en soi–mesme, au contraire de ce mouvement du centre de la terre & succession des signes, autour d'une ligne parallele à l'aissieu de l'Ecliptique; d'Orient en Occident […]" (Blaeu 1642, pp 188–189; the translation is mine).

[5] We read the edition of 1703, in which we can find the *Imprimi potest* given by De la Hirè "Lecteur & Professeur du Roy, & de l'Académie des Sciences", but it has a lot of editions (the sixth in 1751).

*Cosmographie.*[6] Then the third part about construction of spheres is the most interesting one. With reference to the chapter five, in the Section I, *De la Description de la Sphere artificielle selon l'hypothese de Copernic, & de son usage*, there is a summary of Copernican system and its progressive spheres. Bion judges it "simples & n'ayant aucune dépendence les uns des autres". In the section II, *Des Usages de la Sphère de Copernic*, Bion analyzes the three movements of the Earth and explains as individuate them on the globe. The proofs are similar to Blaeu's ones, but more rich of details.[7] By and large, operational instructions are not able to give a definitive prove of Copernican systems. This conclusion was really advanced in the *Advertisement* to the Section II *Méthode pour tracer les Cartes de Géographié tant générales que particulières*:

> In my Boutique on the Quay de l'Horloge du Palace, at the Soleil d'or, there are few spheres, so much exact that they can be built in the Ptolemaic and in the Copernican way.[8]

## 4 Conclusion

In these instruction–handbooks the inequalities against which astronomers fight since long time are not cited: several inequalities of celestial bodies were named *inaequalitas soluta*, if not correlated with the synodical revolution, or *inaequalitas alligata*, if correlated with the synodical revolution[9]; or, in general, inequalities about the determination of the mean motion of the planets.[10] Thus we can see that: (1) the XVII$^{th}$ century

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[6] Bion 1703: Ptolemaic system, pp 10–17; Copernican system, pp 17–25; Tychonic system, pp 22–25; *Système composé* that is the Marziano Capella's system, pp 25–27.

[7] There are not figures in these pages in this edition, but in the later ones (Dekker 2004, p 98).

[8] "On trouve dans ma Boutique fur le Quay de l'Horloge du Palais, au Soleil d'or, des Spheres autant exctes, qu'on les puisse construire selon les Systemes de Ptolomée & de Copernic […]". (Bion 1703, pp 332–333; the translation is mine).

[9] In refer to the Moon the inequalities are well explained in Small 1802, pp 15–16; with respect to Mars, Jupiter and Saturn at pp 22–23.

[10] For a geometrical summery of Kepler's solutions of *inaequalitates* see Small 1804, pp 163–226: Kepler resolves a lot of these problems when he elaborates the

handbooks concerning the construction of terrestrial and celestial globes are used as tools to extend the familiarity and the comprehension of Copernicanism; (2) the Copernican globes and the geometry, on which they are constructed, are not able to elaborate definitive solutions to permit a clear choice between various system; (3) finally and obviously, the history of these scientific instruments let us understand how deep and complex the intellectual and practical effort entailed by the Scientific Revolution was.

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three laws of the orbits of the planets: he uses only an experimental and astrometric method (even if he has a deep metaphysical and theoretic approach), surely helped by the fact that the orbit of the Mars, on which he has a lot of Tycho's observations, is the most eccentric one.

## Suggested Readings

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# Paul de Saint Robert and his *True Meaning of a Tercet of Dante*

**Gianfranco Medici and Federica Maffioli**

**Abstract.** Count Paul Ballada de Saint Robert (1815–1888), man of great genius and scholar of various scientific disciplines, shows with the help of science what is the exact meaning of the verses 22.24 of the I chant of Purgatory. Many commentators on these verses of Dante's (1265–1321) masterpiece, in order to avoid the difficulties of a literal explanation and ignoring the fact that Dante knew very well astronomy, provide only an allegorical and fanciful meaning. The explanation of Saint Robert, on the contrary, is based on the astrophysical phenomenon called "precession of the equinoxes" which was well known to Dante.

Key words: Allegorical, astronomy, Chant I, Commentators, Dante, Equinoxes, masterpiece, Paul de Saint Robert, Precession, Purgatory

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## 1 Purpose and Explanation of Paul de Saint Robert

The Count Paolo Ballada of Saint Robert[1] wrote a memorandum with the intention of clarifying and providing the right interpretation of the thought of Dante on one of the most controversial and debated passages of the Divine Comedy. The memorandum *The True Meaning of a Tercet of Dante* presented in June 1866 at the Academy of Sciences of Torino refers to I chant of the Purgatory, wherein the Poet refers to a well specified astronomic phenomenon:

> To the right hand I turned, and fixed my mind
> Upon the other pole, and saw four stars
> Ne'er seen before save by the primal people[2]

Dante knew very well Astronomy, affirms the Count of Saint Robert and this is demonstrated by the fact that in the Divine Comedy there are numerous astronomical allusions. Without the help of the Astronomy many passages of the Divine Comedy cannot be interpreted correctly.

Even if commentators identify the four stars forming the Southern Cross as the stars to which Dante refers, this does not explain how Dante, who was born in 1265 and wrote his masterpiece at the beginning of 14$^{th}$

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[1] The count Paul Ballada de Saint Robert was born in Verzuolo (Cuneo) in June 1815. As very young boy, he entered the Military Academy of Turin becoming soon lieutenant of artillery, and afterwards professor of ballistic at the Military School of Turin. At 45 years he left the Army for devoting himself to the study of physical and military sciences. He was a member of the most important Academies of Sciences. His life was dedicated to technical–scientific studies: Ballistic, Artillery, Mechanic, Hypsometry, (St Robert 1872, 1873, 1874) Thermodynamic (St Robert 1865, 1870) and natural studies; Botany and Entomology. Very important were his studies of Thermodynamic (Drago 1993; Pisano 2007; Redondi 1974), he was the first in Italy to write about Sadi Carnot (St Robert 1868; Pisano 2013) his work *Principes de Thermodynamique* was utilized in the most important Universities in Europe (Pisano 2013). He had also a great passion for mountaineering and promoted the historical ascent to Monviso in 1863 (Crivellaro P 1998) with his friend Quintino Sella (1827–1884). In the same year they founded the prestigious Italian Alpine Club (CAI). He left his studies and retired in Castagnole delle Lanze (Asti) in 1878 until 1884. He died in Turin in 1888. Recently see Pisano 2013.

[2] Alighieri 1960, Purgatory I, v 22–24.

century, could have known a constellation that was not visible at that time from any known land, until the beginning of the sixteenth century by the first daring sailors. Owing to the lack of a satisfactory explanation, the commentators had to refer to the allegory, defining that the Poet wanted to symbolize the four Cardinal Virtues: Prudence, Justice, Fortitude, Temperance and that only by chance they correspond to the truth, by connecting the meaning of the words "save by the primal people" to the fact that they were both honored by the ancients and then almost forgotten and ignored.

According to Saint Robert, the habit of using allegory in order to explain the difficulties encountered in the Divine Comedy is contrary to the intention of the author. As a matter of fact, the poet warns us in the *Convivio* that "[…] first much always be the literal sense, because it contains the other senses, otherwise you cannot understand it and especially the allegorical one" (Alighieri 1928, Tome II, Chap I). Saint Robert then says that when Dante speaks of the "four stars ne'er seen before save by the primal people" (Alighieri 1960, Purgatory I, v24) he refers to stars actually existing and not only in the imagination, and according to the words of Dante, he literally provides the scientific meaning.

Due to the attraction of the sun and moon on the equatorial bulge of the earth, the axis of this latter, instead of remaining parallel to itself, has a slow conical motion from east to west around the axis of the ecliptic, taking about 26000 years to describe the entire cone. By changing the tilt of the earth with respect to the stars, consequently also changes the position of the horizon of each site in relation to them, other new stars become visible, whereas others become invisible. This phenomenon is called *precession of the equinoxes*, because it anticipates the equinox every year of twenty minutes and a half. In this phenomenon we find the solution of the problems of understanding the words of Dante. Because of this motion of revolution of the earth's axis forty centuries ago the Southern Cross shone in our northern sky. Dante, says Saint Robert, certainly knew this movement almost imperceptible, because it also deals with it in chapter XV of the Treaty II of the *Convivio*, which describes the movement of the starry sphere almost insensitive about one degree in one hundred years. In more recent modern times, this value was corrected to about one degree every 72 years. Dante, continues Saint Robert, certainly well knew the existence of the four stars, as they are described in the catalog (*Almagest*) of Ptolemy (100–178), where they do not form a specific constellation but are united in the *Centaurus* (Delambre 1817).

The astrological address followed by Dante in his masterpiece is undoubtedly the scientific one which is headed by Claudius Ptolemy. Moreover, Ptolemy is mentioned several times (Ceri 2000) in the Convivio by Dante, along with a clear understanding of his theories (Alighieri 1928, Tome II, Chap III, XIV, XV).

## 1.1 The Opinion of Other Scholars

Rinaldo Orengo (1895–1991) writes in his book *Dante Man of Science* (1978): "The Astronomy of Dante in the Divine Comedy and in the *Convivio*, is not whimsical or fanciful: it is exact". Dante had the possibility to know the doctrines handed down by the Almagest, which was translated in 1175 from Arabic into Latin by Gerard of Cremona (1114–1187) and he also had the possibility to know the work of Alfragano (c IX), *De Aggregation Scientiae Stellarum* (Moore 1903) also mentioned in the *Convivio* (Alighieri 1928, Tome II, Chap VI) .

Corrado Gizzi (1915–2012) in his book *Astronomy in the Sacred Poem* (1974) admits that the entire cosmology of the Comedy has been built by the great Poet, on the precession of the equinoxes.

Even Alexander Humboldt (1769–1859) in his Examen Critique (1837) and in Cosmos (1848), writes Saint Robert, attributes a real existence to the four stars of Dante, but explains, as many commentators, that the words "ne'er seen before save by the primal people" (Alighieri 1960, Purgatory I, v24) mean that they were only seen from Adam and Eve. At the time of Ptolemy, around the second century of the Christian era, they were still visible in the most southern parts of the Mediterranean, so it is no wonder that they were known to him and are included in its catalog. Consequently, these invisible stars in Europe at the time of Dante were visible, due to the precession of the equinoxes, to the early inhabitants of Europe, *from the primal people.*

It seems inexplicable to Saint Robert that Humbolt did not notice that the first people had to see the Southern Cross also living in the northern hemisphere. For him the first to suggest that the words "ne'er seen before save by primal people" (*Ibidem*) allude to the effect of the precession of the equinoxes, was the astronomer Joseph Johann von Littrow (1781–1840) in his book *The Wonders of the Sky* published in 1834.

Even the astronomer Ernesto Capocci (1798–1864) in his *Cosmographic Illustrations of the Divine Comedy* published in 1856 also admits the same explanation and confirms that Dante could be very well aware of the existence of the four stars because he knew the catalog of Ptolemy.

### 1.2 Astronomer Zanotti Bianco on St Robert's Work

Astronomer Zanotti Bianco Ottavio (1852–1932) in his *Astrology and Astronomy* (1905) writes: There is no shortage in these verses of the commentaries: maybe there are too much of them. Commentators have worked using their imagination, as usual, copying each other serious errors, ignoring as well the serious work of astronomers and the warnings of Dante himself. Two Italians astronomically employed these tercets, and their names are completely ignored, as their work by *dantologi*. I want to talk about Ernesto Capocci and Count Paolo Ballada de Saint Robert. The first is a Neapolitan astronomer, who in 1856 published a book entitled *Cosmographic Illustrations of the Divine Comedy*. The second is a distinguished mathematician who cultivated science not for earning a living but for pure love. He left lasting traces in various branches of knowledge, he published a work entitled *The true meaning of a tercet of Dante*. In both works there is the correct explanation of verses 22–24 of chant I of Purgatory.

Saint Robert in stating that the "four stars ne'er seen before save by primal people" (Alighieri 1960, Purgatory I, v24) actually exist and are those of the Southern Cross, also asserts that Dante could have known those stars because he had studied and meditated about the Treaty of Ptolemy, although they were long ago disappeared from the horizon of any place in Italy due to the precession of the equinoxes. But the explanation of Saint Robert was totally ignored, as well as that of Littrow and Ernesto Capocci.

## 2 Paul de Saint Robert's Scientific Proof

Saint Robert in the conclusion of his memory consolidates the astronomical theories contained in the tercet of Dante with a clear graphical representation, obviously supported by mathematical calculations. The following table is taken from his memorandum; Saint Robert shows the results of his calculations for the declination and adding the complement of the latitude of 45° obtain the height of α Southern Cross and Sirius on the horizon related to a point located at 45° North latitude (Central Europe), in the period between 13,000 years before Christian era, and 13,000 years after Christian era.

**Table 1** Declination and height on the horizon[3]

| Years | Southern Cross α A | Sirius A | Southern Cross α B | Sirius B |
|---|---|---|---|---|
| – 13000 | – 42° 49' | – 61° 39' | + 2° 11' | – 16° 39' |
| – 11000 | – 35° 9' | – 62° 7' | + 9° 51' | – 17° 7' |
| – 9000 | – 30° 31' | – 54° 52' | + 14° 29' | – 9° 52' |
| – 7000 | – 29° 29' | – 44° 12' | + 15° 31' | + 0° 48' |
| – 5000 | – 32° 9' | – 33° 24' | + 12° 51' | + 11° 36' |
| – 3000 | – 38° 12' | – 24° 17' | + 6° 48' | + 20° 43' |
| – 1000 | – 46° 59' | – 18° 13' | – 1° 59' | + 26° 47' |
| Christian era | – 52° 7' | – 16° 37' | – 7° 7' | + 28° 23' |
| + 1000 | – 57° 2' | – 16° 5' | – 12° 2' | + 28° 55' |
| + 3000 | – 68° 6' | – 18° 16' | – 23° 6' | + 26° 44' |
| + 5000 | – 75° 58' | – 24° 22' | – 30° 58' | + 20° 38' |
| + 7000 | – 72° 38' | – 33° 30' | – 27° 38' | + 11° 30' |
| + 9000 | – 62° 26' | – 44° 20' | – 17° 26' | + 0° 40' |
| + 11000 | – 51° 33' | – 54° 58' | – 6° 33' | – 9° 58' |
| + 13000 | – 41° 47' | – 62° 10' | + 3° 13' | – 17° 10' |

*Legenda*: A = Declination; B = Height on the horizon.

[3] Adapted: Saint Robert 1865–1866, I, pp 598–601.

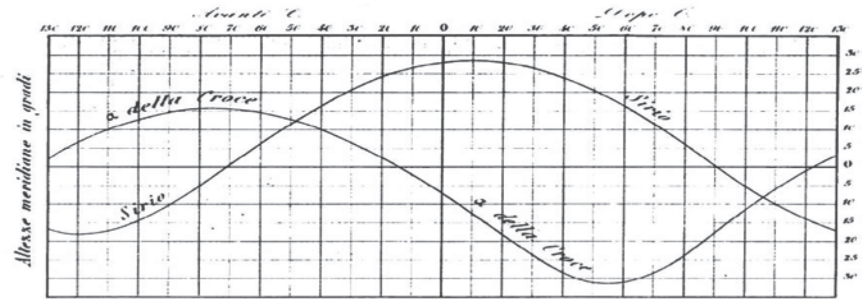


**Fig. 1** The position over the centuries of the two stars for 45° north latitude [4]

From the graph of Saint Robert, it can be inferred that α of the Southern Cross began to be invisible from the "primal people" at a latitude of 45° (Central Europe) 1410 years before the Christian era. It will make itself visible again in the year 12293, and will remain so for 12,062 years before returning invisible for other 13,703 years. The same goes for the star Sirius which nowadays is one of the most beautiful stars in our sky: it will become invisible in the year 9118 and will not reappear on the horizon until after other 9,505 years, thus remaining visible over the centuries for 16,260 years and invisible for 9,505 years.

## 3 Conclusion

Even today, the verse "ne'er seen before by the primal people" (Alighieri 1960, Purgatory I, v24) is the subject of conflicting discussion and argument among scholars of Dante, but we think that tying the proven and documented knowledge of Dante in the field of astronomy to the mathematical and scientific proof of Saint Robert, there is no reason to interpret in a different way the words of Dante.

[4] *Ibidem.*

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# Notes on the Concept of Force in Kepler

**Raffaele Pisano and Paolo Bussotti**

**Abstract.** In this paper we present some historical and epistemological notes to trace a general picture of the concept of force in Kepler with the aim to provide: a) conceptual bases of Keplerian notion of force; b) a stimulus to the Kepler *Forschung* as to this concept.

Key words: Kepler, Concept of force, Astronomy, Planetary systems, Gravitation, Magnetism, Theory of light

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## 1 A Short Introduction

Nowadays the dynamic concept of force is usually associated with Newton standard form, exposed in *Philosophiae Naturalis Mathematica Principia* (1687; 1713; 1726). In particular, Newton defined *Vis insita* (Newton 1726, 1, definition III, p. 3, lines 1–3), *Vis impressa* (Newton 1726, 2, definition IV, p. 4, lines 5–6), *Vis centripeta* (Newton 1726, 1, definition V, p. 4, lines 13–14) and *Vis centripetae quantitas acceleratrix* (Newton 1726, 1, definition VIII, p. 7, lines 4–5). Inside this 8th definition Newton explicitly claimed: "Oritur enim quantitas motus ex celeritate et ex quantitate Materiæ, et vis motrix ex vi acceleratrice et ex quantitate ejusdem materiæ conjunctim" (Newton 1726, 1, p. 8, lines 5–7). Newton succeeded in explaining celestial and terrestrial dynamical phenomena from a new unitary and mechanical point of view. Kepler dealt with the concept of force in a manner different from Newton's. He was partially influenced by other authors whose conceptions we summarize in the following table.

**Table 1** An incomplete sum of *gravity* and *force* conceptions before Kepler

| Author | Main concept | Sources | Comments |
|---|---|---|---|
| Lucius Mestrius Plutarchus[1] | Gravity | *De facie quae in orbe Lunae apparet*. (Goldbeck 1896, pp 10–11; Ihmig 1990, pp 158–160) | Critics to Aristotelian theory of Natural places. Interesting considerations connected to gravity |
| Johannes Buridanus[2] Nicolas Oresme[3] | Impetus theory | | Problem of the motion of a body treated in a manner different from Aristotelian one |

[1] c. 46/48–c. 125/127.

[2] c. 1295/1300– 1358.

[3] 1323–1382.

| | | | |
|---|---|---|---|
| Julius Caesar Scaliger[4] | Motive souls. Motive intelligences | *Exotericae Exercitationes* (1577) (Westmann 2011, p 19) | Aristotelian. Distinction between moving power (efficient cause) and intelligence (formal and final cause). Vitalistic conception |
| Franciscus Patricius[5] | Cosmology based on light action | *Nova de universis philosophia* (1591) (Stanford Encyclopaedia of Philosophy) | The light is an intermediary between corporeal and incorporeal realm. |

Despite many publications are dedicated to the concept of force in Kepler, there is no general agreement among scholars as to important remarks:

1) A significance of Kepler's physical astronomy inside his astronomy.
2) The origin and nature of the different kinds of Keplerian forces.
3) The theory of gravitation in Kepler.
4) The role played by Kepler in the development of the concepts of force.

With regard to the concept of force in Kepler, the problems 1)–4) are the most important from the point of view of history of physics and science. A state of art with regard to the causes of movements concerned with Kepler (at beginning of his scientific activity) was mainly:

1) The movements in the skies were attributed by various authors to *animae, virtutes, vires, intelligentiae, lumina, luces*, but there was no specific definition, either mathematical treatment, or accordance on what these terms meant and how these *forces* acted.
2) astronomy was mathematized, but had nothing to do with the causes of the movements;

[4] 1484–1558.
[5] 1529–1597.

3) The movements and the change of movements on the earth were attributed to the *impetus* that a motor gives to the mobile. *Impetus* theory had, however, many problems, was not universally accepted and had hardly a quantitative treatment.
4) The gravity was a sort of vagueness.

## 2 The *Places* of the Force in Kepler

Kepler was the scientist who tried to unify points 1) and 2) looking for the physical causes of the movements of the celestial bodies in the sky. This is the main contribution of Kepler to that part of physics today we call dynamics. However, he also gave important contributions to the concept of gravity. Nevertheless, Keplerian theory of forces acting in the skies and his theory of gravity can hardly be re–conducted to a common root. In his early work *Mysterium Cosmographicum* (1596) Kepler attempted to determine the physical causes of the planetary paths in the solar system. The book is almost entirely dedicated to the famous theory of the regular polyhedron applied to the disposition and orbits of the planets in the solar system (Field 1988; Pisano and Bussotti 2012): "numerus, quantitas et motus orbium" (Kepler 1596, KGW, I, p 9, line 34).

Kepler argued that, given two planets $A$ and $B$, being $D$ and $d$ their respective distances from the sun, with $D>d$, and $T$ and $t$ their periodical times, the distance has a double effect on the periodical times: 1) because if $D>d$, obviously the orbit of $A$ is larger; 2) because $A$ is slower. Therefore he believed that the following relation exists:

$$\frac{T-t}{t}=\frac{2(D-d)}{d} \qquad (1)$$

this relation can be easily transformed into the following one:

$$\frac{D}{d}=\frac{t+T}{2t} \qquad (2)$$

Since the periodical times of the planets were known, the ratio of the distances could be directly calculated. With regard to the physical nature of the force from which the movements of the planets depend, Kepler proposed two hypotheses: 1) every planet has a moving soul (*anima* *motrix*) whose power decreases in proportion to its distance from the sun; 2) only an *anima motrix* exists; it is in the sun and it acts on each planet in *inverse proportion to the distance sun–planet*. Kepler looks to be favourable to this second hypothesis because, as the source of the light is in the sun "ita nunc vita, motus et anima mundi in eundem Solem recidit" (Kepler 1596, KGW, p 70, lines 18–34. Quotation p. 70, lines 25–26). From a physical point of view Kepler thought: since the power of the *anima motrix* decreases *in proportion to the distance* and since the *anima motrix* produces *velocities* (and not *accelerations*), then the velocities of the planets in their paths are inversely proportional to the distances sun–planets. With regard to the nature of *anima motrix*, Kepler in the *Mysterium* used a language which is typical of a vitalistic conception of the universe, nevertheless, he treats the *anima motrix* with mathematical means. This represents an important novelty. In the introduction to *Astronomia Nova* (1609) Kepler explained the principles on which the *doctrina de gravitate* is based (Kepler 1609, KGW, III, pp 24–28):

1) Everybody stays at rest, unless it is not in the influence sphere of a like body. Kepler speaks of *cognata corpora* and writes: "Gravitas est affectio corporea, mutua inter cognata corpora ad unitionem seu conjunctionem (quo rerum ordine est et facultas Magnetica)" (Kepler 1609, KGW, III, p 25, lines 21–23).
2) A force (*virtus tractoria*) exists between like bodies and it depends on the mass of each body (Kepler 1609, KGW, III, p 27, line 11).

A first conclusion can be drawn: the gravity is not responsible for the movements of the planets in the solar system because for Kepler the sun is not a *cognatum corpus* of the planets. Furthermore, a *virtus tractoria* could determine an attraction, but not an orbital movement. Kepler wants to determine a force for planetary movements, at the same time he is carrying out a real conceptual *Odyssey* to determine the form of the orbits, furthermore he is convinced that the nature of the force determines that form. There is hence a continuous superimposition of the dynamical point of view with the kinematical point of view with many variations of theme in both cases: the kinematical results are correct, but the dynamical support presents many problems. A progressive comprehension of Kepler's concept of force needs some steps to open the tangle of Kepler's tractation: 1) *How did he arrive at thinking that the force is inversely proportional to the distance?* Dreyer (1906, pp 387–388) and Caspar (1948, p 143), think that for Kepler the solar force (*virtus*) acts only in the plane of the planetary orbits, that is on a surface, so that the force diminishes as the circumference of the surface, namely as the radius. In fact, if the force would irradiate from every point – as the light – of the sun, then the "force lines" constitute the surface of a sphere and the force would diminish as the radius–square. Stephenson (1987, pp 72–74) does not agree with this model. Moreover, 2) *What kind of force is the solar virtus?* Being not an attractive force, it is a *virtus promotoria* (force that induces movement) acting thorough a *species immateriata* (Kepler 1609, KGW, pp 240–242 and 350) radiating from the Sun. The *species immateriata* unifies the planets to the sun through a sort of immaterial rays of a wheel[6]. Kepler compares the *virtus promotoria* of the sun with magnetic force (Kepler 1609, KGW, III, chapter XXXIV, pp 242–246), of which an advanced treatment was given by Gilbert in *De Magnete*, a book that impressed Kepler, and with light (Kepler 1609, KGW, III, chapter XXXV, pp 247–248). 3) *what force can make it elliptical an orbit?* This problem is dealt with in *Astronomia Nova* (Kepler 1609, KGW, III, chapter LVII, pp. 348–364), but exposed more clearly in *Epitome* (Kepler 1618-21, KGW, VII, pp 337–342). In Kepler's idea: both the sun and the planets are magnets, therefore beyond the *vortical* component of the force, there is a magnetic component, too. Through considerations based on this presupposition, Kepler proposed an explanation of the fact that the orbits are elliptical, (Kepler 1618-21, KGW, VII, pp 337, lines 20–29). By further specifications, Kepler tried to explain: 4) the movement of the apsidal line (Kepler 1618-21, KGW, VII, pp 338–342); 5) the movement of a planet in latitude (Kepler 1609, KGW, III, chapter LXIII, pp 389–394 and [12], in [9], VII, pp 343–348). One third of the whole introduction to *Astronomia nova* is dedicated to the *doctrina de gravitate* (Kepler, 1609, KGW, III, pp 24–28). The main conceptions of Kepler were the following ones: 1) against Aristotle: no "natural place" exists in the universe to which a certain body tends; 2) no mathematical point can attract bodies. The mutual attraction exists only between bodies; 3) the single parts of a body attract another body whose composition is similar (as seen, Kepler speaks of gravity acting between *cognata corpora*); 4) Kepler introduces the concept of *copia materiae*, that can be translated as "mass". It is uncertain if he attributes the intensity of gravity of a body to the *copia materiae* or to the

[6] The intensity of the force with which these rays move the planets diminishes in proportion with the distance Sun–Planet.

volume (Ihmig 1990, pp 180–189). The movement is a physical condition opposed to the lack of movement (Ihmig 1990, pp 166–186). This means that – coherently with his conceptions in celestial mechanics – the forces have to explain not only the change of movement, but the origin of movement itself (this conception is far from Newton's and modern one). The relation between the forces that determine the movements of the planets around the sun and the gravity is problematic. Kepler is not explicit on this and in the literature there are authors (Goldbeck 1896, pp 19–36) who have tried to connect the gravity of the Sun to its motive force; other authors actually think that gravity has absolutely nothing to do with planetary motions (Davis 1992a, pp. 181–182; 1992b). Others think that gravity is important for Copernican conception of Kepler, but it plays a poor role in explaining the movements of the planets (Stephenson 1987, pp 4–7). No general agreement exists on this problem.

## 3 Conclusion

In Kepler's early work *Mysterium Cosmographicum* and in the second edition of this work (1621), almost at the end of his complex intellectual itinerary, he confirmed the opinion that he expressed in the first edition of the *Mysterium*: "denique quicquid fere librorum Astronomicorum ex illo tempore edidi, id ad unum aliquod capitum, hoc libello propositorum, referre potuit, cuius aut illustrationem aut integrationem contineret" (Kepler 1621, KGW, VIII, p 9, lines 25–28). Coherently with this conviction, the methods that Kepler used in astronomy were invariably connected to geometry and to the possibility to construct the points of the figures he was looking for by rule and compass (in particular p 98). The use of mathematics (algebra) both from a symbolic and conceptual point of view, is almost absent in Kepler's astronomical works, so a mathematical-interpretation of the concept of the force was premature.

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# The Modern Thermodynamics as Based on the Principle of Virtual Work

**Raffaele Pisano and Antonino Drago**

**Abstract.** The principle of virtual work governs some formulations of mechanics which are alternative to Newtonian mechanics. Lazare Carnot explicitly claimed to have founded his formulation on principle of virtual velocities, which for the first time obtained in a theoretical way the characteristic laws of mechanical machines. An analysis of Sadi Carnot's thermodynamics' theoretical premises reveals that most of them represent characteristic features of the principle of virtual work, so it is possible to suggest a formal link between Lazare Carnot's mechanics and modern thermodynamics: two basic principles of the latter one, included the correct formula for the efficiency of a heat engine.

Key words: Thermodynamics, Mechanics, Virtual work, Sadi Carnot, Lazare Carnot

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## 1 A Short Introduction: the Organization of the Theory and its Respective Problem

The thermodynamic theory originated in the book by Sadi Carnot (1796–1832) who studied heat machines considered as the extension of mechanical machines (Carnot [1824] 1978, p 8). The link between the two scientific theories is also theoretically formal (Gillispie and Pisano 2013) when we consider the mechanics in Lazare Carnot's (1753–1823) formulation (Drago 1994, pp 189–198). We list just some of them:

- *The two theories consider not the idealistic abstraction of a material point, but a concrete system of rigid bodies (machines).*
- *The two theories reason en général and therefore use variables that consider the system globally.*
- *Work is the key physical concept.*
- *Each theory poses a crucial problem, whether there exists an upper limit to work production.*
- *First dynamics is considered and then statics. The equilibrium of the system as a theoretical, strategic concept.*
- *The impossibility of perpetual motion is the first physical principle; it is a methodological principle.*
- *From this it follows that constraining reactions cannot make work; that means the principle of virtual work* (PVW) (Drago 1993; Pisano 2013; Capecchi 2012); *which therefore has a theoretical autonomy from the force–cause, which is the basic notion of Newton's Mechanics.*
- *Metaphysics is avoided; neither space nor time is the Newtonian ones; the nature of the force is not investigated by L. Carnot as well as the nature of the heat is not investigated by S. Carnot.*
- *Infinitesimal analysis, then conceived in an ontological way, is avoided.*
- *The specific theoretical problem of both theories is finding the upper limit to the production of work* (Carnot [1824] 1978, pp 6–7).
- *Abstractions are included, but they are operatively approximated. In the theory of mechanical machines the constraints are defined by the relation* $M>>m_i$ *between mass M of the rigid body constraint and the masses* $m_i$ *of the bodies* (Carnot 1786, § XXIX); *so, in the theory of thermal machines, each thermostat is characterized by the relationship* $C \gg c_i$ *between its thermal capacity C and the thermal capacities* $c_i$ *of the bodies in question.*
- *One constraint alone, even if it has an unlimited capacity, cannot produce work* (Ivi, § XXX).
- *No positive work can come from a set of constraints.*

– *Work is produced by the passage of a physical quantity between two constraints. Hence, in thermal machines the work essentially depends from the thermal jump $\Delta t$.*

## 2 The Work of a Gas, In/Out Efficiency and the First Principle of Thermodynamics

*A clear formula for the fundamental quantity of work.*

When Lazare Carnot extends his mechanical theory to hydraulic machines (Carnot 1803, Corollary VI, p 69) using the example of a fluid in a cylinder, a very simple mathematical formula with only two global variables, $V$ and $p$, is used: $W=p\Delta V$. Since Sadi Carnot's time in thermodynamics, the same formula is applied to the exemplary thermal case of a gas in a piston (Carnot [1824] 1978, p 18). Therefore, it belongs both to mechanical theory and heat theory: $W=F\Delta s=(F/S)S\Delta s=p\Delta V$. Therefore, now two variables are known, $\Delta t$ and $\Delta V$, *that are necessary for formalizing the interaction that produces work.*

*Input/output efficiency.*

In a theory, the PVW plays the role of a methodological principle: given an input (virtual movements), it leads to know the output. Lazare Carnot's theory as well, which is based on the PVW, outlines the functioning of mechanical machines, relating a given entrance to the output (Carnot 1786, § XXXII; Kuhn 1969). This theoretical attitude is the same in the theory of thermal machines: given entering heat, to find the work effects, by placing them in relation amongst themselves. A mathematical efficiency $\eta=W/Q$ can be conceived. By uniting in just one quantity, both the heat $Q$, whose nature is uncertain, and work $W$, which is surely not a state quantity (it depends on machines–paths of their internal movements), the notion of efficiency eliminates part of the theoretical problems that the two provide on their own; therefore, the problem need not be solved in advance if heat $Q$ is conserved or not in the passage between the two temperatures; only the dependency of $\eta$ on other state variables of the agent must be considered. In mathematical terms, from the work $W=G(t, V, x, Q)$, with $x$ possible additional variables, we move to the efficency $\eta=W/Q=g(t, V, x)$.

*Equation of state of perfect gases.*

Historically, the state equation was written by Poisson and by Sadi Carnot (Poisson 1823, pp 337–352; Carnot S [1824] 1978, pp 223–234; Drago and Vitiello 1986, pp 167–173) in the same years in which Carnot formulated his theory. Being that for a gas there are only three state variables, we are able to obtain the third variable from the other two; hence, in the previous formula other variables, other than the $t$ and $V$ already seen, can be excluded. Therefore, *the aim of the entire theory becomes that of further specifying the mathematical formula* $\eta = f(\Delta t, \Delta V)$.

*Friction as heat. The principle of the equivalence of heat and work.*

Lazare Carnot's equation for the balance of kinetic energy for the collision of plastic bodies states that the resulting energy is equal to the energy transmitted plus that which is lost; in modern notation:

$$\Sigma m_i W_i^2 = \Sigma m_i V_i^2 + \Sigma m_i U_i^2 \tag{1}$$

In the second part of the book the formula is translated into terms of work (Carnot 1786, § XXXIX Cor. IV, par. XLI Cor. V) which in the case of systems which move by imperceptible degrees, states from the outside the (dynamic) equilibrium of the activity of any mechanical machine (*Ivi*, §XXIV, Cor. II): the work of driving forces equals the work of forces resistant to the machine's motion: $W_M = W_R$. Moreover, in the second edition of his book, Lazare Carnot specifies that when the machine includes springs, a cycle must be considered (Carnot 1803, ft. 8 p 260). He recognizes a case in which collisions occur and also friction occurs (Carnot 1786, §XLVII; Carnot 1803, p 255). This leads to recognize resistant, work as composed by two types of work: purely resistant because there is friction inside and outside the motion of the machine, $W_A$; and that which overcomes external forces in a way which is useful for our aims, $W_U$. Therefore, previous formula becomes:

$$W_M = W_U + W_F \tag{2}$$

On the other hand, this formula merely reiterates (see Eq. 1) in terms of work. As it is well–known from everyday life, the work of friction, $W_F$, turns into heat; in (see Eq. 2) as well the term that represents *the energy of lost velocities*, $\Sigma m_i U_i^2$, suggests the idea of heat – as Leibniz, who L. Carnot supported – had clearly illustrated a century before (Drago 2003, p. 131; see also Oliveira 2013). To translate formula (see Eq. 3) for thermal phenomena, we recall that the thermal machine consumes heat to produce work; therefore the heat $Q$, which plays the role of $W_M$, transforms into both useful work $W_U$ and friction $W_F$; the latter may be considered as $Q'$, heat at a lower temperature: $W_A = Q'$. Therefore, that which interests us, $W_U$, is equal to $Q - Q'$. This expresses the correct formula of the first principle of modern thermodynamics applied to a cycle like that of Sadi Carnot's theorem (Pisano 2010) for a thermal machine:

$$W_U = Q - Q' \tag{3}$$

## 3 Reversibility and Function Efficiency

*The relationship between mathematics and physical notions.*

In Newton's Mechanics the use of infinitesimal analysis is preceded by analytic geometry and kinematics, which make the passage from rational number to real numbers to eventually *dx* (or to limit $\varepsilon$–$\delta$, which, according to Cauchy, obtains a single point) almost natural; by means of the last numbers dynamics is later developed. Instead, L. Carnot, like Gottfried Leibniz (1646–1716), used differential calculus in the applications only, whereas in the foundations he used merely algebraic and trigonometric techniques. Similarly, thermodynamics (for Sadi Carnot as well) does not use infinitesimal analysis a priori, but selects a suitable elementary mathematics which is specific to the various heat transformations of gases (Drago and Vitiello 1991; Drago and Pisano 2005). Moreover, L. Carnot conceived the origin of the mathematical concepts as originated from empiric and operational (Carnot L 1803, pp 2–3). He brought back differential calculus from a metaphysical base to its operational base by writing a book that explained the efficiency of it by means of operative calculations on finite mathematical objects (Carnot [1797] 1813).

*Further theoretical elements: reversibility.*

Lazare Carnot was the first to introduce passive forces (which before him were not conceivable, they would have been *against causes*) and more generally he moved from ideal conditions (even bodies without mass) to real conditions. He clearly established that the efficiency of a machine could range from a maximum until that which is null, according to one condition: the reversibility or not of the process; the reversibility means that the movements occur by imperceptible degrees. This is a pre–condition for using differential calculus. Let us inspect the relationship between mathematics and thermodynamic notions. The near static nature plus the *invertibility* of a transformation that the system undergoes, is none other than the point–wise continuity. In Cauchy's analysis (the common one) this continuity (in a closed and limited interval) implies, through the Heine–Borel theorem (which uses the axiom of infinite choice from infinite sets), the uniform continuity. Hence, in this kind of mathematics the two concepts of near static nature and uniform continuity, which is required for the *integrability* of a function, coalesce; they equate reversibility without requiring any additional physical condition. Instead in constructive mathematics (defining any notion by means of finite algorithms, and hence rejecting both the axiom of infinite choice and Heine–Borel theorem) the point–wise cannot become without additional conditions uniform continuity. This distinction is quite suitable for thermodynamics, where the near static nature of a transformation needs additional conditions (absence of internal friction, viscosity, hysteresis, etc.) to become reversibility. Which, by implying uniform continuity, allows the first operation of differential calculus in thermodynamics: the integral (whereas in Newton's Mechanics the first differential operation is the derivative for obtaining velocity).

*Theoretical completeness of the variables for solving the problem.*

Since efficiency $\eta$ depends on the reversibility of the transformation, in a reversible transformation work will surely be the maximum possible; therefore, we can now treat the work quantity as only $W_{max}$. This is surely valid for thermodynamics as well as the sought efficiency: $\eta=W_{max}/Q$ .

## 4 Conclusion. Carnot's Theorem and the Second Principle of Thermodynamics

*Carnot's theorem.*

It should be noted that already in 1786, to fight against the chimera of an unlimited obtainable work from machines, L. Carnot looked for a theorem (Carnot 1786, p 72). In thermodynamics the theorem was suggested by Sadi Carnot's. It is based on using a cycle of reasoning – as Mach claims Carnot's cycle is (Mach 1986, Chap. XIX) – which associates four transformations, chosen in a way which alternates the two fundamental conditions of the heat/work interaction: the condition of interaction and that of the absence of interaction; the former is chosen in such a way that leaves free, in the efficiency formula, the variable on which work depends, $V$, whereas the other variable, $t$, is constant; therefore an isotherm; the condition of non–interaction can be a transformation either without work ($V$=cost), or without heat ($Q$=0); due to its reversibility, the latter should be chosen. It is unnecessary to repeat the S. Carnot's reasoning here since it is well–known. The result is that the efficiency of any reversible machine *cannot* be *lesser* than that of an irreversible machine operating at the same temperatures, whatever the agent and whatever expansion, $\Delta V$, is carried out, therefore it can only be $\eta_{irrev} \geq \eta_{rev}$. Now the problem becomes that of knowing this function compared to the only temperature variable: $\eta = \eta(t_1 - t_2)$.

*The second principle of thermodynamics.*

Now we note that in Lazare Carnot's mechanical theory the efficiency is maximal when $L_A$ is minimal; that is to say, when there are no friction, vortices, sudden variations in velocity, percussions. Therefore, the efficiency can be set as $W_U/W_M$; that is in thermodynamics, $W_U/Q$ (with $Q$ the heat at the highest temperature), which is maximal when in formula (2) $W_U = W_{max}$, that is, when $W_A$ is minimal; that is, when there is a complete exploitation of the thermal interval in heat, under reversible conditions. At this point, in the hypothesis of the heat–work equivalency, and therefore by the formula (see Eq. 3), we can write:

$$\eta = \frac{W_U}{Q} = \frac{Q - Q'}{Q} = 1 - \frac{Q'}{Q} \tag{4}$$

a formula which, being $Q'$ always lesser than $Q$, shows the existence of that upper limit the theory sought. Additionally, it should be noted that when one links $Q$ to temperature $t$, we can think of this linkage in the simplest relation, i.e. proportionality, $Q=kt$ (roughly, in modern thermodynamics it is the formula of entropy $S$ at the constant temperature); which in formula (see Eq. 4) gives exactly the modern formula of the efficiency $\eta = 1 - k_1(t_1/k_2 t_2)$; and, if $k$ is the same (that is, if the cyclic process is reversible) the sought efficiency formula of a thermal machine is $\eta = 1 - (t_1/t_2)$. This result solves Sadi Carnot's problem.

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# The Developments of English Science and Scientific Popularization between 1700 and 1800

**Arcangelo Rossi**

**Abstract.** In the climate of the late XVIII$^{th}$ century's industrial revolution a new opening took place in England towards scientific education and popularization. This opening can be fully understood only by paying attention to the whole dynamics of the connected social and cultural changes concerning, in particular, the relationships between science and technique. Here I focus the most essential of those changes marking the transition from the XVIII$^{th}$ century's natural philosophy to the XIX$^{th}$ century's English science and technology, accompanied by the development of a scientific popularization also linked to immediate productive interests in an almost consolidated bourgeois society.

Key words: History of physics, English Science XVIII$^{th}$–XIX$^{th}$ Centuries, Scientific Popularization XVIII$^{th}$–XIX$^{th}$ Centuries

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## 1 Characters and Crisis of XVIII$^{th}$ Century's Newtonianism

English scientific development in the XVIII$^{th}$ century was dominated by the great Newtonian heritage, particularly in the main scientific institution of that century, the Royal Society. It was a "natural philosophy", lacking in immediate productive interests, and with an only cognitive interest for technique just considered as an object of curiosity by scientists who were in general devoid of economic worries. Mainly belonging to aristocratic, clergy or high bourgeois classes, in the social order where they operated, at variance with their colleagues in the Continent put in the context of the ancient regime, they generally appreciated the technical inventions carried on by productive classes. Besides, in particular contexts different from London or great English universities like Oxford or Cambridge, a new scientific technological reflection linked to capitalistic interests was developing, particularly in Scotland. That reflection was often of a high scientific level, having fertile contacts with academic tradition, like the cooperation between the chemist and philosopher Joseph Black and the great inventor of the steam engine James Watt. Anyway, English Newtonianism had even before known a series of developments more and more adapted to new scientific and social demands. First of all, Newton's aspect which was most developed in England was the *experimental* one, dealt with in his *Opticks* (1704), at variance with the mathematical science of nature instead dealt with in his *Principia mathematica* (1687). This one was a science which, though it interpreted demands of middle class emancipation and development, remained dependent of the ancient regime. The main inspiration exerted by Newton's *Opticks* on English scientists was instead in the direction of framing experience in "experimental" models on the wave of the largely qualitative models and hypotheses of *Opticks*. In particular, English science accepted Newton's viewpoint according to which the "force" does not preserve in a universe composed of absolutely hard and inelastic atoms. To be true, the first Newtonian models, formulated in dynamic corpuscular terms, still used Newton's mathematical approach itself, fundamentally to describe physical actions as actions at a distance among atomic corpuscles. on the example of gravitational ones. Afterwards, at the middle of the XVIII$^{th}$ century, the attention was more decidedly turned to the experimental side. Then, the enhancement of technique reached the highest level, even to the detriment of Newtonian orthodoxy. Models were developed, also of

Newtonian derivation, but no more at a large but a close distance, because elastic repulsion at close distance of imponderable fluids appeared indispensable to preserve the *force*. This new phase of Newtonianism, very fertile for empirical science, baptised *materialistic* to be countered to more abstract and mathematical mechanism of the previous one, developed in a different environment: instead of English Universities and the Royal Society, new Scottish Universities where there was more attention for productive development. Joseph Black (1728–1799), Watt's teacher in Glasgow, and B. Franklin, were the main protagonists of the phase. The last phase of English Newtonian science of the XVIII$^{th}$ century was in short again mechanist and using mathematics to redefine the contributions of the fluidic approach in more precise, abstract and simplified terms. This trend took place above all again in English universities and the Royal Society. In particular Lord Henry Cavendish (1731–1810) tried to reduce Franklin's elastic and electric fluid to Newtonian mathematical actions at a distance.

## 2 The New Technology and Official Science

The relationship between official science and technology developed more and more in theory and practice. For first, the study of hydraulic machines to improve their rendering, that is above all for economic needs carried on by John Smeaton, raised a debate in the academic science itself, the Royal Society. In fact he did not consider the case of absolutely hard and inelastic bodies of Newtonian atomism, but only the experimentally testable loss of motion in order to reduce it to a minimum. On this same line Watt applied the rendering calculation to engines different from the traditional ones: the steam engines. Then he utilized caloric chemistry whose main organizer was J. Black. Watt then succeeded in putting the principle of energy conservation at the basis of his work, though he did not enunciated it explicitly. It is interesting to consider that chemistry was at the basis of Watt's approach. In fact, at least in the case of chemistry, natural philosophy did not appear to restrict itself to following instead of helping and inciting it.

## 3 The Birth of the New Science

Benjamin Thomson (1753–1814), afterwards Count Rumford, finally advanced proposals inside the official scientific tradition itself of new goals and contents. His exceptional intellectual and practical gifts, united to an absolute lack of scruples, allowed him a very brilliant career. His prevailing scientific interest was at once chemistry, instrument of knowledge and power. Then Rumford dedicated himself to thermology, which he linked to urgent practical interests. But above all friction phenomena put in such evidence the link between thermal and mechanical processes that induced Rumford to draw very general conclusions on heath as motion and not as matter, as it was meant in general by XVIII$^{th}$ century Newtonians. Coherently with his dynamic–phenomenal viewpoint corresponding to the showy dynamism of industrial revolution, Rumford suggested a new organisation frame for science. So, in 1799, was born the Royal Institution, which had as its goal to contribute to the social development through science and technique. It was a program with which Rumford did not identify himself for a generic love for mankind, but for personal advantage. But times were not ripe. Technique was still a question of ingenious individuals, and Watt himself refused , for economic reasons (that is to protect his patents), to expose his models to public as Rumford asked. Then Rumford's organizing ambitions clashed with individual free initiative. His successor as president of the Royal Institution, Humphry Davy (1778–1829), preferred to change line. The new science had to be an object of delight besides utility. Davy addressed the good society with the accents of a brilliant popularizer pointing to the sense of surprise which scientific novelties could arouse in the good, especially feminine society, on which he exerted the fascination of a dandy. Continuing on the close link between science and technique established by Rumford beyond Newtonian mechanism, even though without a mathematical treatment, he based most of his work on Volta's discovery of the electric current. It is symptomatic that, as with Davy, in England a chemical interpretation of the current as an instrument for penetrating the chemical transformations of matter soon prevailed, overcoming the distinction between matter and force typical of English Newtonianism. Davy besides drew several stimuli from the dominant romantic philosophy of nature, arriving at maintaining that all is force and unceasing mutual transformation of forces. Analogous was the evolution of his pupil Michael Faraday (1791–1867), also inspired by Roger Joseph Boscovich's (1711–1787) reduction of matter to pure centres of force, until the 50's, when, after extending this viewpoint to the whole physics with the creation of the field concept, he even eliminated any reference to Boscovich's atomic centres distinct from his *lines of force*. Faraday too marked the Royal Institution which he was called to run after Davy. Devoid of a mathematical training at variance with his great followers Maxwell and Kelvin, he transformed the Institution from Davy's scientific–literary drawing room into a serious experimental laboratory also dedicated to scientific popularization extended to common people. Then knowledge truly began power producer placing the essential requirements, already in the first *thermodynamic* phase of the industrial revolution, of its second, *electromagnetic* phase, by developing its dynamistic and energetic presuppositions. In the meanwhile new demands pressed, of organisation and clarification in analytical and mathematical sense of scientific language, that also permitted more rigorous and systematic technical applications.

## 4 Conclusion

The individualistic and amateurish character of English science, also common to the Royal Institution, depending on the changeable personalities of its directors, was finally indicated as a cause of decline by the famous mathematician Charles Babbage (1792–1871). Then in 1831 the British Association for the Advancement of Science arose by reconciling several points of view, including Faraday's. Though individual initiative remained, the demand of mathematical, not only experimental, specialization was almost out of discussion. In the new context there developed, together with higher levels of experimental precision, new powerful analytical instruments, even overcoming the XVIII$^{th}$ century Newtonianism: the field concept more and more mathematized, and statistical mechanics with its elastic atoms according to the point of view of energy conservation and of kinetic theory. In the meanwhile Faraday, who anyway showed to appreciate the first attempts at mathematizing his ideas by Maxwell and Kelvin, said he was incompetent to judge them. He rather carried on his researches, often misunderstood, of a science which, pioneeringly born in the industrial revolution, lived the crisis of XVIII$^{th}$ century

Newtonianism, expression of a reality previous to the industrial revolution, and the birth of the first forms of scientific technology.

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# The Techniques and Methods of Italian Architectural Drawings of the Early 20th Century

**Antonella Salucci**

**Abstract.** This paper shows the results of a research experience carried out on a significant body of original architectural competition drawings, with the aim to highlight a number of interesting aspects of architectural education and the communication of architectural ideas within history of sciences. This graphic evidence, connoted by its twofold nature of didactic experimentation and professional practice, anticipates the characteristics of the drawings produced by the protagonists of the so–called *Roman School*: multifaceted figures active as *Professors*, *Designers* and *Masters*.

Key words: Academy, Competition drawings, Visual impact, Graphic inventory

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## 1 A Premise

This text proposes a reflection on Italian architectural drawings from the early 20th century. Each consideration is deduced from the direct observation of texts and drawings, some of the latter unpublished and extraordinary in their visual impact. The objective is that of retracing a period in the history of Drawing through the ideal visions created by aspiring candidates of the *pensionato di Architettura* at the *Accademia di San Luca*. These works, related to scholastic essays, completed inside this illustrious Roman academy, delineate a number of interesting aspects of architectural education and the communication of architectural ideas. They are representative of the methodology adopted by the Academies, prior to the foundation of Schools of Architecture, to educate new students in the preservation and valorisation of Italian artistic traditions. This graphic evidence, connoted by its twofold nature of didactic experimentation and professional practice, anticipates the characteristics of the drawings produced by the protagonists of the so–called Roman School: multifaceted figures active as professors, designers, architects and Masters. The large quantity of works analysed belongs to a rich corpus of drawings and documents conserved by the *Archivio Storico* of the *Accademia di San Luca* (Marconi, Cipriani and Valeriani 1974), hereinafter ASL.

The reading of the textual documents found amongst admission test reports, in addition to the architectural drawings – guidelines, conclusive reports drawn up by the president of the jury, individual reports submitted by the designers of each project – are of particular interest and still valid today, as well as serving as the foundations that substantiate the analysis of the spectacular architectural images examined.

The considerations and references accompanying integral texts and original images may be further investigated in a publication presenting the results of a study of drawing entitled *La rappresentazione della città: acqua e architettura* (*The Representation of the City: Water and Architecture*) and edited by the University of Chieti–Pescara research unit as part of a co–financed research programme (Salucci 2011; 2012).

## 2 Comparative Evaluation

Evidence of the origins of the *Accademia di San Luca* in the ancient *Università delle Arti della Pittura* can be found in the miniatures illustrating the title page to the *Libro degli Statuti quattrocenteschi*,

conserved in the ASL archives: the image depicts two representatives of the Università and two consuls submitting the rules to Saint Luke. Its actual transformation into an Academy occurred with the solemn foundation ceremony held in 1593, and is symbolically referred to the work of Prince Federico Zuccari, who instituted the teaching of Drawing as a prevalent discipline in any academic education. Documents testifying to the institution of the selection process – founded on a comparative assessment – for accessing the *pensionato in Accademia* in the three Arts of Architecture, Sculpture and Painting exist from 1677. Openings arose periodically in relation to funds bequeathed by members of the academy.
The years of the *Concorso Lana* (1913) and the *Concorso Montiroli* (1912) preceded the foundation of the *Scuola Superiore di Architettura* by only a few years. Instituted on 31 October 1919 and inaugurated on 18 December 1920, it was temporarily housed in the Istituto di Belle Arti in *Via di Ripetta* in Rome. It was during this period that Gustavo Giovannoni (1873–1947) – director of the *Scuola Superiore di Architettura* from 1927 to 1935 and president of the selection committee on both aforementioned occasions – conceived of the innovative figure of the "integral" architect, delineating the prerequisites to be possessed by young students of architecture (Giovannoni 1916). This conception was strictly linked to the affirmation of an education in Drawing as a foundational methodology and prevalent discipline in the training, of the hand and mind, of students at the Scuola Superiore di Architettura (Unali 2003, p 65).

At the time of the institution's foundation, access to the three–year pensionato represented the most sought after milestone in the aesthetic education of any artist, whether a resident or visitor to Rome; it was reserved for the most noteworthy artists, and linked to successful participation in a competition specific to each of the three Arts (Salucci 2011, p. 240).

The *Manifesto* of the selection process for accessing the pensionato in Architecture allowed for students of Architecture twenty–five years of age and under, with at least one year of lessons in Architectural Theory and Practice at the *Regio Istituto di Belle Arti* or *the Regia Scuola di Applicazione per gli Ingegneri in Rome*. Aspiring candidates were invited to participate in an extemporaneous, six–hour preliminary exam, held in the halls of the Academy. Candidates were to resolve the plan, elevation and section of a building in the Greek or Roman style. The same theme was to be further developed over the successive six months, through the development of two and three–dimensional drawings and details, accompanied by a text describing the layout, construction and technological aspects of the building. Requests included: all plans at 1:100; all internal sections and the main elevation at 1:50; a detail of the façade and a main part of the interior at 1:10; a coloured elevation of the building measuring 0.55 by 0.75 centimetres. Selection rules clearly stated that the three–year *pensionato* be awarded to the candidate who, in the unquestionable judgement of the committee, demonstrated the most ingenious solution and absolute merit.

An academic professor proposed by the candidate and confirmed by the Committee, defined under article eleven as a *professore dirigente* (managing professor), was responsible for tutoring the student during the three years of the *pensionato*, guiding him in the preparation of the two main submissions. The first, established for the 1 December of the first year of the *pensionato*, called for the submission of a drawing of a classical monument of Roman architecture, accompanied by texts, dimensions and full–scale details; the second submission, due at the end of the second year, consisted of the drawing of a grandiose *imaginary structure* in the classical style, fully developed in all of its parts. At the end of the *pensionato*, the *Manifesto* foresaw a final, three–day public exhibition of all drawings produced during the three–year period; some of the images became the property of the Academy. Successful candidates were awarded a diploma during the General Assembly, an important awards ceremony, characterised by lavish set design, and considered a public moment *par excellence* in the life of the Academy and an important Roman tradition.

## 3 Repertory of Drawings

The competition in the field of Architecture represent an aspect of the Academy's activities that led to the production of a repertory of drawings, both immense in size and extraordinary in content: indispensable material as much for observing and comprehending those aspects linked to the communication of ideas as those connected with the education of future masters, professionals and professors.

The objective of academic representations was the conception of a virtual architecture focused on demonstrating the design skills and cultural level achieved by students. These fascinating and unmistakable drawings are the result of consolidated processes of selection that remained unaltered for many years; there are scholars who claim they are not true projects but instead "compositional exercises of a formal nature"

(Sainz 1986:28). This activity of consolidated methods and procedures produced an enormous quantity of artistic and architectural material: a graphic inventory of paper architecture without precedent. They are design "intentions" and simulations of reality, expressed in monumental drawings and captivating designs, developed using various methods, tools and techniques. These unique pieces were produced expressly for the concorsi: spectacular and monumental drawings that brought popularity and cultural prestige to the institutions promoting them.

Academic teaching was focused on the concept of unity in the Arts "through" drawing, a foundational moment of learning, according to a method re–proposed in nascent Italian Schools of Architecture. This is made clear in the list of disciplines comprising the Academy's course calendar: Theoretical Architecture, Practical Architecture, Elementary or Decorative Architecture, Nude Drawing, Sculpture, Mythology, History, Archaeology, Anatomy, Geometry and Perspective, Etching in Stone and Copper, Hydraulics Applied to the Arts. These educational activities took place for the most part in truly compositional environments almost exclusively in occasion of periodic comparative evaluations for admission to the *pensionato*. Under these circumstances, aspiring students confronted three levels of drawing complexity: an exercise in surveying a monument; an extemporary exercise; and a complex project at the urban or territorial scale. Drawing was the medium for demonstrating the degree of preparation, capacity for comprehension, and prefiguration achieved. This structure refuted any experimentation or openness toward all that was new, alienating itself from its era, and nurturing a contested graphic culture based on virtuosities and exasperated realism (Bonetti 1913; see Fig.1).

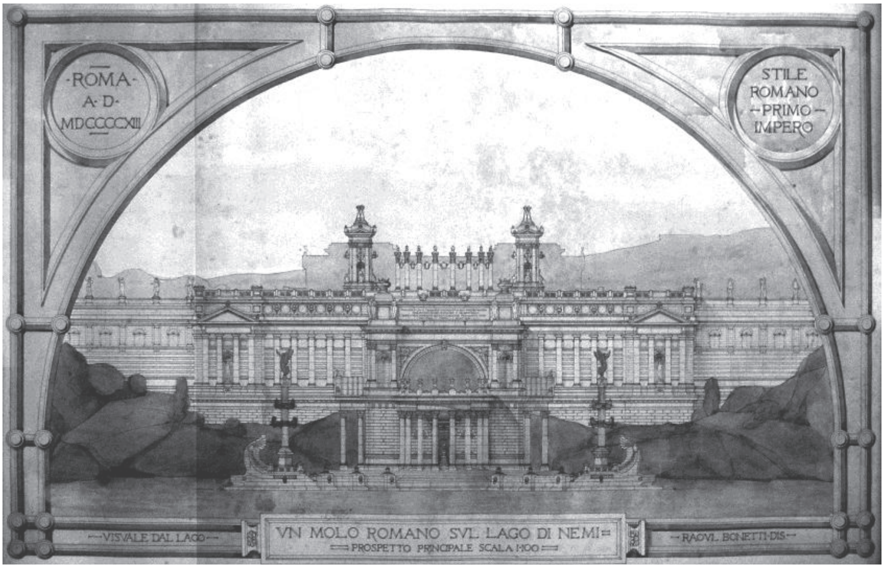


**Fig. 1** Raoul Bonetti. Winner of the Concorso Lana 1913[1]

## 4 Conclusion. Archaeology of the Drawing

The direct observation of the original drawings produced for admissions tests and prepared as part of the two complementary phases of ex–tempore drawing and final submission, allow us to retrace diverse sources of interpretation in architectural drawing from the early 20th century. An initial aspect regards the thickness of the paper, which consents a tactile, olfactory, visual and acoustic perception of the drawing; the narrowing of the visual field achieved by large–scale drawings exalts the density of information. A relevant aspect regards the technique of representation, from which the emotional process that generated the finished image unequivocally transpires; traces of graphite, annotations, reference lines and latent geometries compose a system of "imprints" of the past, a sort of archaeology of the drawing that makes it possible to comprehend the idea

[1] *Un molo romano sul lago di Nemi. Prospetto principale. Visuale dal lago.* Scale 1:100. Ink and watercolor. Original cm. 130x85; detail. ASL Disegno 3345. (Marconi, Cipriani and Valeriani 1974, vol. 2).

represented (Magnago Lampugnani 1985). The attention focused on the layout of the drawing, an expression of the development of the graphic arts, is united with the controlled and subtle sign found in the preciseness of the architectural detail and the settings: refined drawings overlapping transparent liquid and rarefied skies crossed by clouds and the wind. The precision of chromatic expression constitutes a fundamental part of the scholastic essay. Materials and the treatment of surfaces are rendered as coloured fields, fine hatchings, shading and blurs. Diluted ink and monochromatic and coloured water paints describe the light and shadow of architectural space; in plan the traces of the pen dipped in India ink overlap geometries laid down in pencil, to contain the liquidity of a field rendered with rapid strokes of watercolour.

As requested by admission standards, the academic drawings referred essentially to two methods of representation: perspective and orthogonal projection. These may have eventually been integrated with shadows and enriched by the use of colour; what is more the simultaneous use of vertical and horizontal sections is frequent; an advanced technique that amplifies the control of the mental image.

To conclude these observations it can be said that the most fascinating aspects of these drawings include that connected to their latent utopian vein. As the construction of the work represented was not the final objective, these projects were configured as exercises in style, the exhibition of skills, didactic exercises that speak of surfaces, envelopes, decorative details and formal aspects. In conceiving utopian simulations of the classical world, aspiring students demonstrated skills and abilities in the three souls of representation – geometry, surveying and design – and the principal connotation requested was that of verisimilitude. An image comparable to a photographic *still*, which is limited the circumstances in which it was frozen, it is not exhaustive, it has no synthetic narrative, and it does not pretend to communicate the multiplicity of the meanings of the architecture it represents, but instead expresses and captures a utopian fragment.

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# The Variable Radius Cartography: the New Experimental Discipline

**Giancarlo Scalera**

**Abstract.** It is an aim of the present extended abstract to show that in the last century cartography was used in a way more or less complex, more or less intertwined with other disciplines and databases, not as pure representation or in the spirit of the simple *fits* that supported continental displacements, but as experiments of greater significance with a value of proof in favour of the planet expansion, and providing suggestions to Physics, Astronomy and Cosmology about probable incompleteness of their current conceptions.

Key words: Variable radius cartography, History of cartography, Expanding Earth

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## 1 A Short Introduction

The expanding Earth conception is today considered the major alternative to the plate tectonics, and is going to overcome the rival theory on the basis of a larger number of interconnected explanations of phenomena, not only in the field of Geology and Geophysics, but also in more general fields (Scalera 2012). Its main merit is that it has freed the Earth sciences from subordination to Physics and Cosmology. The expanding Earth suggests strongly that our knowledge of the physical world must be based starting from the only celestial body be experienced directly, taking as a *test–body* what lies beneath our feet, and not *viceversa* boxing the properties of the planet so that does not contradict the still uncertain cosmological principles.

The typical experiments that it was necessary to perform under this conception were of a new kind, namely cartographical experiments. It can be said that the expanding Earth transformed the cartography in experimental science.

## 2 The Beginnings

The idea of significant changes in the size of our planet has no placed stable roots in the scientific–philosophical culture before the second half of the 19th century, with the rise of the first ideas on the expansion of the Earth. Previously, only hints in pure academic disputes, or unaware realization of world maps – with Earth radius less than real – were proposed (such as the map that Toscanelli sent to Columbus; Chiarelli 1992) without any practical follow–up in the technical field of cartography. Why the ancient philosophers have not seen the global change in volume as feasible problem can have several causes. One of these may be the presence of different ideas about the shape of the Earth holding the debate at a lower level: the sphericity of our planet still needed to be discussed and ascertained (Scalera 1999).

The XIX$^{th}$ century perfects and leads to a higher level of awareness the first insights of Abraham Ortels (Ortelius 1527–1598), Francis Bacon (1561–1626), René Descartes (1596–1650), François Placet (1666), Thomas Burnet (1635–1715), Theodor Christoph Lilienthal (1717–1781), about possible continental matches of shape and displacements. In full XIX$^{th}$ century began to circulate ideas far more precise on a possible ancient closeness between the continents today facing on the Atlantic (Morello 1979). In 1838 Thomas Dick (1774–1857) – American theologian and philosopher – wrote about the

> […] striking correspondence between two sides of the two continents to which we have adverted" [Africa and South America], and that the "prominent parts of the one corresponding to the indentings of the other.[1]

Also Alexander von Humboldt (1769–1859) – in 1801 and 1845 – wrote on the geometrical and geological similarity between the coasts of America and Africa, hypothesizing that the Atlantic had been flooded by a catastrophic event. Often reproduced in texts of the history of science is also the cartographic exercise by Snider–Pellegrini (1802–1885) – Italian–American traveler, essayist, Biblical commentator – who in two engravings represented the globe before and after the fracturing and separation of the continents.

It is not difficult to imagine how much influence all these ideas had to have for the birth of ideas about significant expansions of the planet. Richard Owen (1810–1890, American chemist and geologist who studied in Hofwyl on the Swiss Alps) in his book proposed the principles of what himself called (Owen 1857, p. 22) *Anatomical Geology*, with the Earth and other heaven bodies seen as biological organisms that grow by accumulation of external materials. (Owen 1857, p. 84). It is very interesting to read his description (Owen 1857, p. 14, p. 20, p. 75) how from the complete set of geological mapping available in 800s his idea sprang of a global solution, from which it will be born the first example of mapping of an expanding Earth. Considering the closure of the Atlantic and the overlap of South America on Africa, his Earth was to have a radius of not more than 4000 kilometres. After him no more until the next century.

## 3 XX$^{th}$ Century: the Birth of Experimental Cartography

In 1928 J.A.H. Kerkhoff (under the pseudonym *Aero–dilettant*) published a series of paleogeographic globes on which the modern oceans

[1] Dick 1838, p 93.

disappeared. In 1933, with the same artisanal methods of transferring the continental outlines from a sphere to a smaller one, O. C. Hilgenberg represented three different geological epochs on three different radius wooden globes, and, later, for the first time mapped paleopoles with their site–pole segments of meridian. Hilgenberg (1933, 1962), Barnett (1962), Creer (1965) and in Russia Kirillov (1958), provided proofs that an Earth completely covered by continental crust was possible at a radius about 0.55 of the actual one. It was showed that at intermediate radius it was impossible to close huge sea gulfs – like Tethys – that appeared to be artifactual. Creer (1967) published his *cartographical experiment* also on the sumptuous Runcorn's *International Dictionary of Geophysics*, which greatly contributed to legitimate and promote the ideas of the expanding Earth, and the new wave of publications appeared from the seventies onwards (Carey 1975, 1976; Hilgenberg 1974; Chudinov 1976, 1980; Owen 1976, 1983; and many others). Even today the traditional method of Hilgenberg, Barnett and others is followed by senior researchers (Vogel 1983, 1990) and younger geologists (Maxlow 1995, 2012). The junction between old and new is represented by the passionate and continuous work of Klaus Vogel in Germany as *globe–maker*.

In England Hugh Owen (1976, 1983) applied the methods of traditional cartography to the variable radius one. His *Atlas of Continental Displacement* was, in the 70s and 80s, for this discipline, a real milestone. While in the field of constant radius paleogeography the adherents to plate tectonics created many computer codes of automatic mapping (Bullard et al. 1965; Smith and Hallam 1970; Scotese et al. 1979; and many others) in the variable radius field few tried to reach the same task. In 1972 in United States a first very simple attempt (but was not furtherly developed) came from a private, R.B. Perry, followed by the still not–computerized Atlas of Owen, and both them constituted inspiration for the construction of a variable radius mapping code at INGV, with which it is now possible to represent paleopoles, site–pole segments of paleomeridian, and their uncertainty ellipses (Scalera 1988, 1990, 2007). In all paleogeographic reconstructions of the various authors, cartography is used in a way more or less complex, more or less intertwined with other disciplines and databases, not as pure representation or in the spirit of the simple *fits* that supported plate tectonics, but as experiments of greater complexity with a value of proof in favor of the planet expansion. Today a common feeling among followers of the expanding Earth is that it is now necessary to develop an interactive and *user friendly* computer code, which could be distributed or used in the web.

## 4 Conclusion

The old way to use the cartography as simple scaled plotting of the existing things of the Earth was slowly overcome by the need to represent the same objects (continents, rivers, terrains, mountains, etc.) in different positions than the actual, as soon as the paleogeography took in consideration not only regressions and transgressions of the seas but also the mobilistic concepts of displacements of large fragments of the Earth's crust (Wegener 1912). This new way of mapping was not fully experimental: its advanced aim was to prove the goodness of the fit of continental outlines. Nothing of new was suggested to physical sciences.
Instead, a new and deep aim was defined with the use of cartography in the expanding Earth framework (Scalera 2007). In this case the success of the paleogeographical reconstructions take on a new and more general significance. The fields involved are not only geology, geodynamics, tectonics, but unavoidable suggestions are provided to physics, astronomy, cosmology (Scalera and Jacob 2003; Scalera, Boschi and Cwojdziński 2012) – leading all these disciplines toward perspectives of a more dynamic, extremely *mobilistic*, view, showing the inadequacy of many current conceptions. The experiments in cartography are surely *lowest cost*, nevertheless their results should be considered *heavy*, like those coming from the *great physics* of the giant particle accelerators.

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# Art and Science of Building in the Work of Giuseppe Damiani Almeyda

**Cesare Tocci**

**Abstract.** The work discusses the changes that have occurred in the structural control of architecture in the second half of the XIX$^{th}$ century. The starting point is supplied by the examination of two projects of the architect–engineer Giuseppe Damiani Almeyda, representative of two successive moments of an evolutionary process whose current outcome seems to be a deep fracture between the fields of architecture and engineering. Giuseppe Damiani Almeyda constitutes a paradigmatic figure of that particular historical moment in which the transition from the ancient art of building to the modern strength of materials occurs.

Key words: Damiani Almeyda, Art of building, Strength of materials

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## 1 A Short Introduction

Far away from the sectoral specialization of today's technical culture, and endowed on the contrary with a surprising competence on various fields of the architecture, the architect–engineer Giuseppe Damiani Almeyda (Capua, 1834–Palermo, 1911) constitutes a paradigmatic figure of the historical moment, dating back to the second half of the XIX$^{th}$ century, in which the transition from the ancient art of building to the modern strength of materials occurs (Benvenuto 1981, Carocci and Tocci 2010).

This crucial passage in the history of mechanics is exemplified in this work considering two projects of Giuseppe Damiani Almeyda – the metallic cover of the Politeama Theatre in Palermo (1875) and the reconstruction of the masonry dome of the Marsala's Cathedral (1893) – that are emblematic of two different planning conditions (from the viewpoint of both the mastery that the designer exhibits on the technical context within which he works and the theoretical knowledge available for him on the same context) and, moreover, representative of two successive moments (although chronocologically inverted) of the process that has led to the gradual replacement of the synthetic approach of ancient architecture with the analytic one of modern engineering.

Detailed accounts of both projects can be found in Barbera 2008, Carocci 2009, Tocci 2010, Barbera et al 2011. In this paper they are read again from a structural point of view focusing the attention mainly on the metallic cover of the Politeama whose design history highlights significant features of the turning point occurred in structural mechanics during the second half of the nineteenth century.

## 2 The Dome of the Marsala's Cathedral

Damiani Almeyda was charged for the reconstruction of the collapsed dome of Marsala's Cathedral in 1893. He decided to rebuild a masonry dome, according to a choice that nowadays could perhaps demand endless arguments about its acceptability from standpoint of the restoration theory but represented, in the nineteenth century, a rather natural choice.

This choice puts Damiani Almeyda inside a technical context he knows perfectly. Masonry technique is, at the end of XIX$^{th}$ century, in its full maturity and several Architecture's Treatises guarantee to engineers its complete mastery. The situation is equally clear also with regard to the structural analysis. The calculus of vaulted structures has reached, since the end of XVIII$^{th}$ century, a state–of–the–art arrangement. Damiani Almeyda proves the conceptual inconsistencies of the independent arch model, still used for the vaulted structures at his time and discusses a richer model capable to explicitly account for parallel actions proposing a personal hypothesis in order to remove the problem of the indeterminacy of the pressure's line (for detailed references about structural analysis' works in the period see Benvenuto 1981; Nascè 1982).

Despite of the complete mastery that Damiani Almeyda exhibits of the technical and scientific context inside of which he moves, the way he follows in designing the reconstruction of the Marsala's dome represents, as a matter of fact, an ancient approach. This is because the static behaviour is governed by the geometrical shape, by virtue of the particular structural typology and constructive technique that make the equilibrium problem overriding with respect to material stresses, and involve the need to prevent kinematic mechanisms rather than to limit internal strains and stresses. Thus, the architectural invention and the static compatibility are two undividable moments of a same designing process and the very formal solution is, in a sense, ancient (a classic double–shell dome instead of the new model made of three superimposed domes dating back to Saint Paul's Cathedral by Christopher Wren).

## 3 The Metallic Cover of the Politeama Theatre in Palermo

The condition in which Damiani Almeyda designs the metallic cover of the Politeama Theatre is very different from the viewpoint of both the constructive technique and the structural analysis tools.

In the seventies of the XIX$^{th}$ century, the iron work is still a cutting edge technique, although it has achieved, in the decade 1850–1860, levels never more reached, neither at the end of the century. In the same years (1850–1880), stimulated by the development of steel construction, structural mechanics acquires its final form and the main ways through which it will develop emerge clearly: energy theorems, displacement method and force method. However, though theoretically clarified, many problems still remain unaffordable for the operational difficulties related to their resolution and, above all, structural mechanics had not yet come to a level of clarity and formal simplicity such that it could constitute an immediate design tool. In such a situation the great nineteenth–century engineers often relied on experience and instinct and made recourse, as a current practice, to simplified models.

The design of the metallic cover of Politeama must be analysed in this context. Damiani Almeyda was charged for the construction of a Politeama Theatre in Palermo, by the Municipality, in 1865 and, in the next year, he was ready to deliver the project. The theatre was inaugurated in 1874 without the cover, which Damiani Almeyda worked to in the years 1874–1875 and that was completed in 1877. The structure of the cover – that spans on a horseshoe shaped space whose axes measure 50m and 30m respectively – is described in a masterly way in the extraordinary drawings of Damiani Almeyda (see Fig. 1) and clearly explained in his calculation memory (Damiani Almeyda 1875).

The cover consists of two overlapping domes. The former is made by twenty–four cantilever trusses with parabolic intrados – "a quadrilateral that because of a similarity of form and function, I call Crane" (Damiani Almeyda 1875) –, simply supported on cast–iron columns (the shortest on the scenic arc wall), anchored by means of half trusses to the perimeter wall and linked together at different levels, at the support, at the free end and at intermediate points:

> between adjacent cranes there are frames (panneau) which constitute some kind of hoops, [...] with the aim of destroying any tendency to bending or shape changing, in such a way that [...] the whole system of meridians and cones is comparable to the joints of a masonry dome.[1]

"Resting like a lid and firmly attached to the edge of the upper throat circle [of the underneath dome], is the central vault, which I call Lantern" (Damiani Almeyda 1875, page s.n.), that is the second dome of the cover system.

[1] Damiani Almeyda 1875.

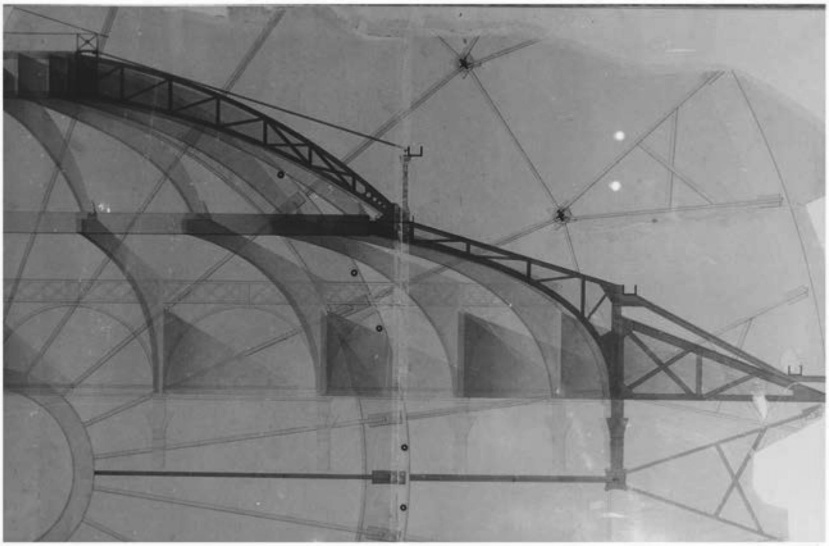

**Fig. 1** Politeama theatre: drawing of the project[2]

As he will show in the design for the Marsala's Cathedral, Damiani Almeyda is perfectly able to govern the static behaviour of a dome system (and, significantly, he refers to masonry domes in the calculation memory for the Politeama), but the difficulty to control analytically its mechanics in the case of a (highly) statically indeterminate three–dimensional truss, drives him to model the structure as an assembly of plane (independent) systems, each of which can be easily calculated and, moreover, represents an actual working mode for the structure, should not develop, for any unpredictable reason, the more complex shell behaviour.

[2] Civic Gallery of Modern Art Empedocle Restivo, Palermo (Drawing photography from Damiani's Private Archive; courtesy of Paola Barbera)

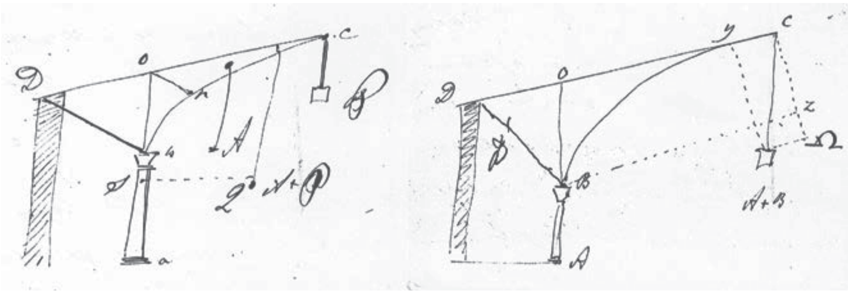

**Fig. 2** Politeama theatre: sketches for structural analysis[3]

These plane systems are the individual cranes considered as independent one from the other, each subjected to the load transmitted by the superimposed lantern, and balanced thanks to the anchorage into the perimeter wall supplied by the half trusses. For each crane, the mechanical behaviour can be easily controlled by means of simple equations of equilibrium – "the principles of modern graphical statics, resting on the properties of reciprocal figures, give us the most elegant solution method" (Damiani Almeyda 1875, page s.n.) – in the implicit and comforting assumption that the shell behaviour of the actual system will increase the safety margins of a structure that the designer wants to be, nonetheless, stable by itself (see Fig. 2) – "the crane will make its own obligation without the wings of the hoops, without the truss at the support wanted by Arioti who did not understand the project, even without the upper throat circle" (Damiani Almeyda s.d., page s.n.).

Anyway, aware of the inadequacy of his analysis methods, Damiani Almeyda does not hesitate to ask for help his old teacher in Naples, Giuseppe Battaglini (1826–1894), and to call for an expert consulting even Alfredo Cottrau (1839–1898), an European authority in the field of metallic carpentry. Moreover, besides the difficulty of managing such a complex structural system, he had also to reply to the objections that were continually moved, in the hostility climate that surrounded the yard of Politeama, questioning the feasibility of the proposed solution for the metallic cover. He was so forced to exhibit assurance even if its doubts were strong and to proceed with sharp assessments where the reasoning should be softened and articulated. That explains the otherwise strange

[3] Damiani's Private Archive, 1869?; courtesy of Paola Barbera.

statements contained in the report by means of which Damiani Almeyda answers to the comments of the Municipal Committee established to judge the great metallic cover. He goes as far as to deny the possibility of the mechanical behavior he had clearly identified in his calculus memory (the shell behaviour) – “during the study, a poor reinforced dome, with its meridians and parallels, fell first; it fell and will never rise again […]. The reinforced dome with meridians and parallels is mechanically impossible. In fact, the thrust at the support will disfigure its shape, and each parallel will diabolically tend to become a circle” (Damiani Almeyda, s.d., page s.n.) – and to present the simplified model used for the analyses as the actual structural system – “I used the word Cranes not for similarity in shape, though there is, but for identity of mechanical function. And if I used the word “Meridian” I did it not in a constructive sense but with an absolutely stereotomic meaning” (Damiani Almeyda, s.d., page s.n.).

## 4 Conclusion

The attitude assumed by Damiani Almeyda in designing the cover of the Politeama defines – by contrast with the traditional conduct followed in the project for the Marsala’s dome and by comparison with the manner of the great nineteenth–century iron engineering – a very interesting example of quantitative, even if synthetic, approach for the structural control of the design of architecture.

Although irreversibly belonging to the scientific world of modern engineering, Damiani Almeyda is still, unquestionably, architect in the very sense of the word, i.e. able to embrace, in the only operation of making architecture, a lot of diversified problems – structural, formal, functional, economic.

In the present age, in which the objectives of architecture and engineering seem to diverge irreversibly, the approach of Damiani Almeyda identifies a possible way to overcome a cultural and technical division that current forms of structural control – based on increasingly refined computational tools – have certainly contributed to broaden. That approach constitutes a suggestion for the current culture that, breathlessly running after the detail, often risks to lose sight of the entirety.

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Tocci C (2010) The structural control of architecture in two works of Giuseppe Damiani Almeyda. In: Cruz PJS (ed) Structures and architecture. CRC Press, pp 159–166

# The Scientific Work of Antonio Maria Jaci in Messina

**Maria Luisa Tuscano**

**Abstract.** Antonio Maria Jaci (1739–1815), born in Naples, spent his life teaching mathematics in Messina. His research interests concern both theoretical aspects and applications in astronomy, navigation and physics with personal contributions praised in his biographies. His commitment to the problem of determining longitude in the sea, the complex design of the *Meridiana* for the Dome of Messina, the attempt to solve the irreducible case of cubic equations, constitute an effective witness of a lively and prolific commitment that deserves a critical analysis also thanks to the discovery of additional documents, currently under consideration in collaboration with the astronomical Observatory of Palermo.

Key words: Jaci, Observatory, Astronomy, Meridiana

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# 1 A Biographical Sketch

**Fig. 1** Antonio Maria Jaci[1]

Addressing the scientific profile of Antonio Maria Jaci requires a preliminary caution. The biographers often have lingered on his life adversities, neglecting the most significant aspects of the personality of this mathematician–astronomer. Hence, in this report we will try to build a biographical reference mainly referred to his cultural activities, limiting human aspects to the conclusive references.

## 1.1 The Early Period (1739–1780)

Antonio Maria Jaci was born in Naples on 15 October 1739. His parents, Nicolò, Neapolitan, and Flavia Ferrara, from Messina, embroiders of tapestries, died prematurely. With the help of his maternal uncle Annibale, Antonio Maria moved to Messina to study at the prestigious College of the Jesuits, founded in Messina in 1548, which guaranteed an excellent education. At eighteen years old Jaci became a doctor in mathematics, philosophy and medicine, even gaining the decision of priestly ordination. He became a priest in 1765 coherently living his vocation by adopting a sober way of life. During the following years he lived with discretion studying Leibniz's theories by reading the books of Wolf. His interests were concerning four topics: Mathematics, Astronomy, Navigation and Physics. Carmelo La Farina (1786–1852) in the biography of Antonio Maria Jaci (La Farina 1836) confirms these studies indicating the presence of some manuscripts in the Museum of Messina. Jaci manuscripts, originally present in the Museum of Messina, were: *Elementi analitici contenenti l'intero corso dell'analisi, la natura del caso irriducibile e i primi rudimenti del calcolo differenziale ed integrale; Esame del sistema Newtoniano, ed una nuova teoria dei colori; Trattato degli orologi solari.*

[1] Drawing of Orazio Coppolino (Sarao 184, plates annexed).

Unfortunately these works during the 19th century were then scattered as the Annals of the City built (Oliva 1893) by Gaetano Oliva (1843–1938).

In 1780 Antonio moved to Naples, where the cultural debate in private circles was lively and they were thriving military schools. There he attended two scientific personalities, Vito Caravelli and Giuseppe Saverio Poli, having the opportunity to convey his competences in the field of ballistics. The circumstances of his resignation in the competition for a professorship of mathematics to avoid moral compromises are not entirely clarified. His stay in Naples, though brief, revealed positive for Jaci, who held a more effective and manifest cultural engagement once back in Messina.

## 1.2 The Years of Social Commitment (1781–1815)

Once returned to Messina, Jaci witnessed, unscathed, to the devastating earthquake of 1783 that left the city in ruins and highlighted the disasters due to the Spanish repression of 1674 and to the serious famines caused by the commercial activity decline. King Ferdinand IV of Bourbon accordingly intervened with a project of reconstruction and development based on upgrading of port infrastructure and on extending the free port to the network of artisans and entrepreneurs of Messina. Beyond determining the port recovery, this circumstance successively provides the needs of the English settlement. In this context the city of Messina assumed a considerable role in the Mediterranean, that resulted in a partial recovery of social welfare and a more lively circulation of ideas. In this climate of renewal, Jaci stepped forward as Professor of mathematics and philosophy in the Seminary of clerics; at the same time he attended the library of Luigi Caccia, landmark of intellectuals from Messina. His argument brought him a great esteem and the acceptance for the Reale Accademia Peloritana with the nickname *Il Sicuro.* Jaci's studies dealt with important scientific problems. His long engagement was that of determining the longitude in the sea for which he presented three papers at the Institute of Longitudes of London, which had banned a contest for an accurate method but easy and with a not expensive (Sobel 1996) application. In the first of three works Jaci proposed the use of an hourglass with mercury and thermometer (Jaci 1785), with a procedure that actually had not an easy implementation onto a ship. The judgement was not positive, but he persevered, and in 1798 he introduced an astronomical method, "horizon of longitude" (Jaci 1798).

The Commission of the contest said that the method was not the one they were looking for but it was however the best among all the other received.

This fact converged on Jaci additional estimates and confidence, from which emerged the assignment by the Accademia Peloritana for the project of a prestigious meridian line for the use of seafarers. Destined to the Mercantile Exchange, the Sundial was built into the floor of the Cathedral and opened in 1804, resulting as a truly unique instrument. It should be noted that at that time Jaci was already nearly blind but his willingness to study did not decrease. In the last two years of life he will face indeed two other study commitments.

**Fig. 2** Plates from the Cathedral of Messina[2]

The first will be the book *The resolution of cubic equations*, published by his student Giuseppe Felice Stagno. In it Jaci faces *the irreducible case*, a classic unsolved of Algebra, which had been formulated already in 1539 by Girolamo Cardano (1501–1576) and that involved other mathematical celebrities among whom Niccolò Tartaglia (1499/1500–1557), Rafael Bombelli (1526–1572), René Descartes (1596–1650), Isaac Newton (1642–1727) and Gottfried Wilhelm von Leibniz (1646–1716) (Gatto 1994). The second effort will be the last work on the longitude at sea, *Addition to the horizon of longitude* (1813), which, according to his biography, was stolen by a visitor. Antonio Maria Jaci spent his last years in modest living conditions, passing away on February 5, 1815.

[2] Stafford and Ball, 1860, *infra*.

## 2 Recent Studies on Antonio Maria Jaci

The dispersion of Jaci's manuscripts is certainly a disadvantage in the critical reading of his scientific personality. It is believed, however, that the works submitted to us are already a staple for proper exploration, as also emerges from some research already undertaken in this regard. In the nineties, thanks to the identification of a 19th–century engraving of the ancient meridian line of the Messina Cathedral (Sarao 1841; Tuscano 2001), it was possible to deepen the study of this complex instrument, today unfortunately no longer observable because of the damages of 1908 earthquake, and, after the restoration, because of 1943 bombing.

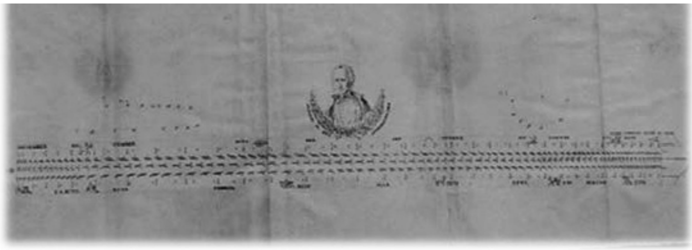


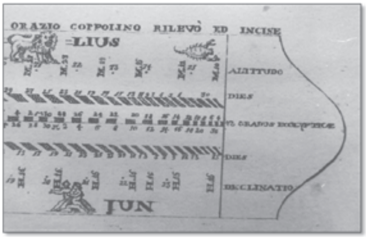
**Fig. 3** Jaci's meridian line[3]

This Meridian line was unique because it provided all solar ephemeris also taking into account the four–year cycle for the leap year.

> It consists of white marble slabs 5 palms wide and long pal 85 onc 6. In the middle of each slab is observed the meridian line, divided in signs and degrees of the ecliptic, using inlaid rectangles of various colors. On either side of the meridian, two curved bands are divided into inlaid trapezoids of different colours, corresponding to the days of the year. The distance between these two bands corresponds to the apparent diameter of the Sun, and to the left, every five days is noted the change in the noon, according to the Italian hours and civil. Observed also at a greater distance from the sundial, the other two lines, formed by small inlaid circles colored, one of which represents the degrees of declination and the other grades of heights at noon. [...] it was observed that the bright image of the sun at noon indicated, with its minor axis, the day of the month, the degree of the ecliptic, the declination, the height of the culmination, the hour of noon,

[3] Drawing of Orazio Coppolino (Sarao 1841, plates annexed).

and the apparent diameter of the sun, filling, with its light, curvilinear space.[4]



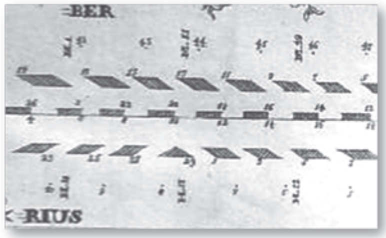



**Fig. 4** Particulars of the *meridian line*[5]

From the same source we learn that the laying of the first stretch of the Sundial in the floor of the Church took place in mid–December 1802; from another source (Sarao 1841) we know that it was completed in 1804. The tool, all in marble, 22.08 m long between the solstitial points, ran across the nave, near the main door.

Jaci devised a gimmick for the introduction of the leap year, inserting a triangle, between the trapezium–shaped indications of the calendar days; the base of the triangle corresponded to 1° longitude on the average. The diameter of the solar image, at the time of culmination on February 28th and 29th during the leap year, touched its extreme points in correspondence of the proper degree of ecliptic. In the three following years, the diameter retreated, six hours each time, indicating the end of February on the vertex and the midpoints of all sides of the triangle; for the other days of the year a similar expedient was applied on the vertices and sides of the trapezoids (Tuscano 2001, 2005). Jaci also distributed 11'13" along the meridian line, according to the canons of the Gregorian Reform.

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[4] [The translation is mine]. *Foglio di letteratura, scienze arti e commercio di Messina,* 8 gennaio 1803. The article is anonymous but Jaci collaborated to paper. This newspaper periodical was published in Messina, only in 1803 (January 1/25, June 18, Fiumara L and Nobolo G).

[5] Drawing of Orazio Coppolino (Sarao 1841, plates annexed).

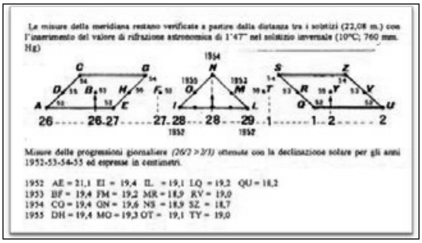


**Fig. 5** Diagram of operation in the four–years cicle[6]

Thus, it was re–established the correspondence between tropical and calendar years. The mathematical complexity faced by Jaci for this project is mainly proved by the fact that the indications of the Sundial were read synchronously on the minor diameter of the solar image.

In 2012, the INAF–Osservatorio Astronomico Giuseppe Vaiana of Palermo, has started the analysis of some manuscripts related to Jaci's contribution in solving the problem of determining the longitude at sea[7]. The physical method described in Latin by Jaci in 1785 was published in Italian in 1787. Being a skilled scientific–instrument maker, he probably underestimated the complexity of its application. The astronomical method, written in Italian in 1798, involved the use of two octants to operate two measurements of the altitude of the Sun or a star and moon to the nearest 15 minutes of degree. Jaci also provided the experimental results obtained at sea with the assistance of the General Danero, governor of Messina, and the Commander Faustini. The prestige of these people and the shipments of the manuscripts by military channels involving even Lord Hamilton, are symptomatic of a political interest surpassing the tenacious enthusiasm of the mathematician. Indeed, achieving an appropriate solution for the calculation of longitude at sea assumed a strategic importance in the Anglo–French conflict: this pushed Jaci to be very prudent to assure his manuscripts would arrive at the Institute of London without being intercepted by the French navy. The third work, published

[6] Tuscano 2001, p 186.

[7] The original documents, kept at Cambridge University, consist in the texts of the first two works sent to properly appointed Commission and later published, and a group of letters enclosed. Reproductions of these manuscripts of Antonio Maria Jaci are currently examined by Ileana Chinnici (INAF – Osservatorio Astronomico Giuseppe Vaiana, Palermo) and Maria Luisa Tuscano.

by Jaci in 1813, improved the earlier two ones by reducing the errors, but to great disappointment of the author, who had become blind, it was not supported by experimental tests.

## 3 Conclusion

Antonio Maria Jaci represents an interesting piece to deepen the knowledge of certain circumstances that outlined in Messina at the turn of the 18TH and 19th centuries, both in science and in society. In particular the fortunes of its Meridian line deserves to be considered, Sundial that perhaps partly exists under the current floor of the cathedral. As much interesting is his third work on the longitude in the sea, probably tied to political events of the moment rather than stolen. Hence the need to deepen and update the study of this figure.

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# Galileo's Use of Practical Knowledge

**Epaminondas Vampoulis**

**Abstract.** In this paper a new look upon Galileo's *Discorsi* is proposed, a look based on the use of practical knowledge made in this major work. It is interesting to note that Galileo places the three interlocutors of the dialogue in an arsenal, and that this place determines the subject of the conversations they will have, especially of their conversation on the problem of the resistance of matter to fracture. The study of this problem in the *Discorsi* is related to significant practical consequences as well as to the work which is done in the arsenal. According to Salviati and Sagredo who open the dialogue, one can acquire knowledge in the area of mechanics by making use of the knowledge accumulated by the artisans who work in the arsenal. To be more precise, the total amount of the observations one can acquire in the arsenal does not contain just those gathered by the artisans themselves, but consists of a larger group of observations some of which come from their predecessors. Having in their minds the total amount of these observations, some artisans of the arsenal are according to Salviati well equipped in order to develop their own thoughts by using their own reason.

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Accordingly, the fine use of reason comes after the collection of a certain number of observations and rational thinking is presented as the outcome of the existence of these observations. So, in the opening paragraphs of the *Discorsi* we find ourselves in front of a very well calculated presentation of the way Galileo thinks but also works.

I believe that we are entitled to read these passages as a presentation of a pattern containing all the steps through which Galileo proceeds in order to attain a rational comprehension of the physical world. Such a pattern seems to take experience as its starting point and proceeds as follows: for Galileo, observations made attentively and systematically have the power to yield rational explanations of the facts. This procedure entails the transition from observations to well organized experiments, given that these experiments are the means through which a rational theory elaborated in all of its details is constructed.

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# Giordano Bruno and the Proportional Eight Spike Compass

## Valentina Zaffino

**Abstract.** The proportional eight spike compass, invented by Fabrizio Mordente (1532–1608), is an instrument that much interested Giordano Bruno (1548–1600). It could measure the infinitesimal fractions of the angular degrees and calculate the proportions between lines, geometric shapes and solids, working on the proportionality and commensurability of angles and segments. This new precision in calculations confirmed Bruno's thesis of the existence of the physical minimum as opposed to the Aristotelian thesis of the infinite divisibility. So far scholarship has mainly tackled the philosophical and historiographical aspects of this issue; we on the other hand will investigate the mathematical and geometric implications of Bruno's claim.

Key words: Renaissance, Compass, Bruno, Mordente, Divisibility, Antwerp, Trifigura

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## 1 Giordano Bruno and Fabrizio Mordente

The proportional eight spike compass, invented in 1567 by the Salernitan mathematic Fabrizio Mordente (1532–1608), drew the attention of Giordano Bruno, who with this tool started his study of the technical and mechanical aspects of Renaissance culture and science, and proposed a philosophical and mathematical interpretation of his results. Modern studies have mainly tackled the philosophical and historical aspects of this question. What we will investigate here are rather the mathematical and geometrical implications of Bruno's arguments, in order to sketch the empiric reason in Giordano Bruno's philosophy of nature. In order to reconstruct Bruno's metaphysical interpretation of Mordente's compass, Filippo Camerota's study and, of course, Bruno's works must be mentioned. In 1586, Giordano Bruno wrote four works on Fabrizio Mordente's compass: *Mordentius*, *De Mordentii circino*, *Idiota triumphans* and *De somnii interpretation* (Bruno [1586] 1957).

## 2 The Role of the Compass in the History of Science

The compass is a tool usually made up of two equal-length hands, interconnected by a joint allowing a relative inclination between these. The Institute and Museum of the History of Science, in Florence, offers an important exposition and description of the most valuable compasses produced during the centuries: the division compass, for splitting lines; the nautical compass, for calculating sailing routes; the spherical compass, for measuring the diameter of cannon balls; the topographic compass, for calculating angles of position and terrestrial distances; the reduction compass and the proportional compass.

Notably, the last two compasses should be considered. Both the reduction compass and the proportional compass are based on the Euclidean geometry properties of similar triangles and are used to draw some quantities having a predetermined ratio with respect to one another (De Bernart 2002, p 119). The reduction compass is used to copy the drawings on a smaller or bigger scale; it has two crossed hands, a fixed or movable center and its opposite spikes form the ratio 1:2, 1:3, etc. The most famous proportional compass is the geometric or military one invented by Galileo. Generally, proportional compasses have, on their hands, various proportional scales, needed to define the ratio between lines, geometric figures and solids. There are three kinds: with crossed hands, similar to the reduction compass such as the Commandino or Bürgi one; with eight spikes, such as the Mordente one; with flat hands, such as Galileo's compass (Camerota 2000, pp 6–7).

## 3 Fabrizio Mordente's Compass

Fabrizio Mordente invented a tool that would be used mainly for astronomical observations, replacing the astrolabe; in fact, the uses of this invention soon became various. He proposed several different versions of the same proportional compass and published many works on the functions of this instrument. The first one was illustrated by the engraver Paolo Forlaniand and presented in Venice in 1567; the second description was written by Gasparo Mordente (the inventor's brother) and dedicated to Emperor Rudolph II in Antwerp (1584); the third variant, published in Paris in 1585, is the version which Giordano Bruno was interested in; the publications of 1591(Antwerp) and that of 1598 (Rome) were harsh replies to Bruno's texts; Michel Coignet (1549–1623) became editor of the last version of Mordente's compass. Mordente's invention is also called *trisesto*, since it can be used as a common compass, as a reduction compass and as a proportional compass (Camerota 2000, p 48). It is a computational tool employed to solve several mathematical and geometric problems: to divide lines, to square circles, to determine territorial triangulation and to estimate the height of the stars. But it is mostly useful to measure the infinitesimal fractions of angular degrees and to compute the ratios between lines, geometric shapes and solids, since it is based on the proportionality and commensurability of angles and segments. Bruno was very much interested in this technical and theoretical aspect. The science of residuals (Camerota 2000, p 85) is the foundation of Mordente's tool and the purpose of the compass is mainly to find a new way to divide and measure a continuous magnitude in a higher number of parts than both the ancient and the modern scientists had been able to do.

The mechanical principle of Mordente's method makes the spikes overlap at the fractions of the straight line. Repeating this task many times, one will finally measure the unknown fraction, which was not included in the previous data: a proportion will be established between the integer and its minimal parts, and the fractions of the continuous extension will be calculated "ad ultimas partes" (Aquilecchia 1957, p 38), up to the physical minimum. The Parisian compass is provided with adjustable and sliding pointers, perpendicular to the axis of the two hands of square section, equipped with coaxial fixed spikes. The first version of Antwerp (see Fig. 1) is equipped with a ruler with various proportional scales divided into 60 equal parts. The second version of 1585 (see Fig. 2) is replaced with a so-called *trifigura*, since it offers three different ways to calculate the fraction of a straight line.[1]

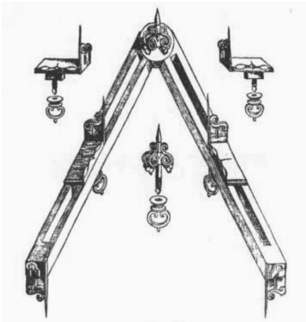

**Fig. 1** Antwerp, 1584[2]

With regard to *Trifigura* we have:

I) Draw a straight line AB, divided into twelve equal parts, and oppose the line AC, thus forming a right angle. Take on AC the segment DC, equal to one of the twelve parts, and from the point D draw a line parallel to AB, called DE, as long as you wish. The aim is to find the value of the fraction of BF of AB: recopy on DE the segment DF, equal to BF, draw a line through C to F intersecting therefore AB at the point G. Since the proportional properties of similar triangles AC : CD = AG : DF, therefore AB : BF = AG : DF. Referring to the thesis of the commensurability of the minimum, Bruno wrote interesting lines in the *Prima demonstratio*[3] of the *Mordentius*. In the following a plate of his reasoning:

1 For geometric demonstrations see Aquilecchia 1957, pp 45–46. See also Camerota 2000, pp 46–48; Bruno and Gabriele 2001, p 303.

2 Mordente [1584] 2000, p 142.

3 "Partes illae comprehensae inter A et G notabunt tibi minuta quae erunt novem cum aliqua ignota fractione. […] ignota illa definienda accipiatur: et […] ponatur super linea D E et operare ut prius, quoadusque ad complementum

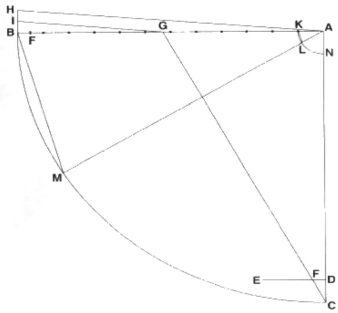


**Fig. 2** Trifigura,1585[4]

II) Draw the segment BH, perpendicular to AB and having a length equal to one twelfth of AB, join H with A and recopy on BH the fraction HI, equal to BF, of which you want to calculate the value; from I plot the line IG, parallel to AH. A proportion will thus be established very similar to the one of the previous case (in this case AB : AG = BH : HI).

III) Consider the orthogonal quadrant AKN, with radii equal to the twelfth part of AB; the chord KL be equal to the fraction that you want to measure, and also draw the chord BM, obtained extending the line AL as far as the point M on the arc BC. AG can be computed recopying BM on AB, obtaining a proportion again (in this case AB : BM = AK : KL). With reference to the recent demonstration, Bruno's woodcut and text are not consistent with Mordente's argument; nevertheless Bruno took this third way of calculating the unknown fraction as the one to be preferred among the three proposals, since it does not produce a cross section, but a section at right angles.

minutis secunda, secundis tertia, et id genus alia subiunxeris". (Aquilecchia 1957, p 45).

[4] Bruno and Gabriele 2001, p 303; see also Aquilecchia 1957, p 45. Image: *Ibidem*.

## 4 Bruno’s Metaphysical Interpretation of Mordente’s Compass

Fabrizio Mordente and Giordano Bruno met in Paris in 1585 and Bruno immediately saw in Mordente’s innovation an extraordinary tool, useful for technical and geometric-mathematical purposes, and indispensable to give a practical foundation to Bruno’s atomist philosophy, and to scientifically support the notion of ontological and physical minimum, which is the ground of Bruno’s philosophy of nature. The first two works written by the philosopher on the proportional eight spike compass are *Dialogi duo de Fabricii Mordentis Salernitani prope divina adinventione ad perfectam cosmimetriae praxim*, followed by the appendix *Insomnium*. Mordente is described as a brilliant person, god-like and discoverer of the minimum (Aquilecchia 1957, pp 31–32). The extreme precision of the calculations made with the new compass provided Bruno with some objective data on which to base his atomistic theory of the matter. Mordente rejected the metaphysical interpretation of his invention, and Bruno’s reply to Mordente’s dissent is expressed in two further works: *Idiota triumphans* and *De somnii interpretatione*, which mocked Mordente, but not his invention. The reasons for the disagreement between Giordano Bruno and Fabrizio Mordente show us the special use of the compass made by the philosopher, and the metaphysical theory on which Bruno’s atomistic math is based. He admitted the infinite only as being infinitely big, in the cosmological sense, postulating the existence of innumerable worlds and a cosmos of infinite dimensions; however, he rejected the existence of the infinitely small and, rather, claimed the existence of the minimum, which in Bruno’s philosophy is physical, geometric, and metaphysical. Notably, the corpuscular nature of matter finds in the atom the physical minimum and Mordente’s compass is a useful tool to calculate the value of the smallest size. Mordente, however, while theorizing the existence of the fractional minimum part, asserted that there is an almost infinite number of mechanical applications that can be performed on the same line. In the *Idiota triumphans* Bruno harshly criticized the inconsistency of Mordente’s theory, which, according to Bruno, was due to the lack of both the mathematical and philosophical knowledge of his opponent (Aquilecchia 1957, pp 12–14). In particular, he claimed that the theoretical uncertainty depended on a wrong interpretation of the Aristotelian physics, that the Salernitan mathematician saw as the speculative foundation of his invention (De Bernart 2002, pp 207–211).

The Aristotelian theory of natural minimum distinguishes the divisibility of the matter from the divisibility of the form (Aristotle 2011, I 4, 187b 35–188a 13): from a quantitative point of view, for Aristotle there is no minimum size (Aristotle 2011, I 4, 188a 11–12), and only in the qualitative movement can there be something in itself indivisible (Aristotle 2011, *Physica* VI 5, 236b 17–18). The statement in the *Physics* that the separation cannot be concluded (Aristotle 2011, I 4, 188a 5–6), was clearly understood by Mordente in a materialistically and atomistic sense, without taking into account that for Aristotle the mathematical divisibility is not the same as the material divisibility. The mathematical and geometrical quantities are infinitely divisible since they don't inhere to a substance, but the concrete quantities cannot be indefinitely divided – nor increased to infinity – as the radical change of matter prevents the form being conserved in a particular body (Aristotle 2011, I 4, 187b 35–188a 4). Therefore, Bruno could not ignore Mordente's serious mistake, where Aristotle's physical theory was taken as the philosophical justification of the application of the proportional compass, through which Mordente tried to reach the fractional minimum of a mathematical – thus, abstract – quantity, but associated with matter (Mordente [1584] 2000, p 133). At the same time, the Aristotelian concept of infinite divisibility of the form lead Mordente to admit an infinite number of mechanical applications which could be performed by the compass on a same line.

## 5 Conclusion

Giordano Bruno, here disregarding the Aristotelian distinction between abstract divisibility of the number and concrete divisibility of the substance, saw in Mordente's compass a technical tool able to scientifically and mechanically validate the existence of the physical minimum, which therefore results to be determinable and commensurable.

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# A Structural Analysis of the Timber Trusses in Italy (1800–1950)

**Emanuele Zamperini**

**Abstract.** Until the mid–19th century timber trusses were designed on empirical basis thanks to a centuries–old experience; they couldn't be analysed with the theory of statically–determinate trusses, because loads weren't applied in the joints, hypothesis required to ignore the static indeterminacy. In the late 1850s a specific structural analysis method was developed for timber trusses, considering rafters as continuous beams on rigid supports. Ignoring the deformation of intermediate supports, such analysis didn't satisfy constitutive and strain–displacement equations. Even if since the 1870s the theoretical developments allowed the exact calculation of statically–indeterminate structures, often engineers still resorted to empiricism, or simplified methods.

Key words: Timber trusses, Theory of structures, Statically indeterminate structures

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## 1 Timber Trusses before the Mid–19th Century

Before the 19th century, a multitude of local carpentry customs characterized Italian timber trusses. The well–established tradition in the construction of this kind of structures allowed architects and carpenters to design them on empirical basis (Rondelet 1810), with redundant members not always suitable from a structural point of view, and with static schemes difficult to be analyzed with the modern theory of structure. Although some initial attempts to use elementary methods of the theory of structures in the design of timber trusses date back to the 1820s (Cavalieri 1826), empiricism kept to be predominant throughout the first half of the century.
Since the late 18th century, the development of iron industry led to profound changes in the production and processing of building materials. On one hand this allowed the spread of new kind of trusses, made entirely of steel, on the other it led to the employ of metallic members in substitution of timber ones in the traditional type of trusses. These two facts were of great importance in the development path of application of theory of structures to trusses. In absence of a specific building tradition, the spread of metal trusses required the development of appropriate structural analysis methods: around 1850s the theory of statically–determinate trusses was therefore elaborated (Timoshenko 1953). The employ of iron members in timber trusses contributed to give rise in engineers to the need for structural assessment also in traditional structures.

In Italian timber trusses, the rafters are usually made of a single continuous squared log from the joint with the tie–beam to the ridge, and they are supported in intermediate point by secondary members (struts, etc.); the purlins usually charge the rafters with loads placed at close range, so that they should be better considered as a span load. Many attempts to apply the theory of statically determinate trusses to timber trusses were carried out (Morin 1853) but they conflicted with the peculiarity of these structures, and they leaded to heavy simplifications (i.e. considering the rafters discontinuous at the supports given by the secondary members of the truss, or the loads applied only in the joints). Indeed the theory of statically–determinate trusses could not be rightly employed with timber trusses because loads were not applied in the joints, hypothesis required to ignore the static indeterminacy of the structure.

## 2 The Theory of Continuous Beams and Its Influence on the Analysis of Timber Trusses

A general solution for statically indeterminate beams was already elaborated in the 1820s by Claude–Louis Navier (1785–1836) (Navier 1826): analysing continuous beams he considered the reactions of intermediate supports as the statically indeterminate quantity. However, for beams with more than two spans, this approach becomes unsuitable, because all the unknown are present in each of the equation necessary to solve the problem. A subsequent method was elaborated by Benoît Paul Émile Clapeyron (1799–1864) in 1849, but published only in 1855 by Bertot[1]. Particularly, he assumed the bending moments at the intermediate supports as hyperstatic unknowns and elaborated the so called three moments equation. The employment of this method made it possible to analyze continuous beams in quite a simple way, and it laid the groundwork for further studies on statically indeterminate trusses.

### 2.1 Bresse's Method for the Analysis of Trusses

In 1859 Jacques Antoine Charles Bresse (1822–1883) exposed a new method for the analysis of static indeterminate timber trusses in his *Cours de mécanique appliquée*. Rafters were studied as continuous beams on the rigid supports given by struts or other secondary reinforcing members and they were considered as charged by span loads; the analysis of the rafters was easily conducted thanks to the three moments equation. In his handbook Bresse showed the application of this method to some simple timber and mixed trusses, such as a timber truss with struts and the mixed Polonceau trusses (see Fig.1).

### 2.2 The Spread of the Bresse's Method in Italy

A few years after the publication of Bresse's manual, Celestino Sachero (1821–1908) wrote (1864) an essay on the strength of roof structures in

[1] For an extensive discussion of the events that led to the enunciation and dissemination in the technical community of the method of the three moments see Timoshenko 1953, pp 144–146.

which he analysed all the most common timber and mixed trusses employed in Italy with the Bresse's method (see Fig. 1). Sachero was the esteemed director of the Italian School of Application of Artillery and Military Engineering, and the authoritativeness of his work favoured the diffusion of this method among the officers of the Corps of Engineers (Turri and Zamperini 2009), while civil handbooks still presented more simplified methods that schematized timber trusses as statically determinate structures.

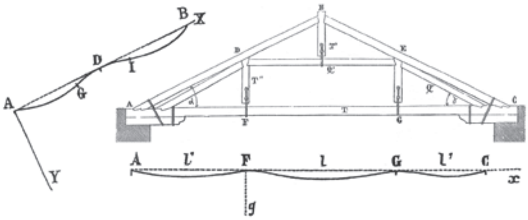


**Fig. 1** Analysis of a Palladio truss[2]

In the 1860s the spread of graphic statics favoured an easier employment both of the theory of statically determinate trusses and of Bresse's analysis technique (Caveglia 1876). In 1879 a second attempt to diffuse the latter in Italy was made by Cesare Ceradini (1844–1935) who published an essay (Ceradini 1879 ) that – as well as the one by Sachero – aimed to provide a draft to analyse the most common trusses.[3]

## 3 The Energetic Analysis of Structures

In 1858 Luigi Federico Menabrea (1809–1896) enunciated the so–called principle of least work to which he gave general validity:

> When an elastic system is put in equilibrium under the action of external forces, the work developed by the effect of tension or compression of the links between the various points of the system is a minimum.[4]

[2] Sachero 1864, p 250.

[3] This corroborate the thesis that in Italy at that time Bresse's method was still employed almost exclusively by military engineers.

[4] Menabrea 1858, p 1056.

In his graduation thesis (1873) Alberto Castigliano (1847–1884) revised the mentioned principle and expanded its field of application to many kind of structures, among which the statically indeterminate structures with bent members; he also showed a series of applications to hyperstatic timber and mixed trusses (Capecchi and Ruta 2010). Thereafter many engineers published technical papers in which they applied this theory to various types of wooden trusses (Candellero 1890; Chiarle 1891). Nevertheless, the complicated computations made Italian architects, civil engineers, builders and carpenters employ this method very rarely for timber and steel–timber trusses; in most cases until the mid–twentieth century they continued to design empirically with the reproduction of well–established models or with the aid of tables, to use simplified formulas, or more rarely the method by Bresse.

## 4 Old Methods for New Trusses

Since the last decades of the nineteenth century, the complex changes in constructions and materials processing started to relegate the use of timber trusses to minor constructions, always employing steelworks in major structures. However, after the First World War and during the Fascist autarkic period, the lack of steel imports made its price grow and, consequently, its use decrease. Therefore, while traditional timber trusses kept to be realized, engineers began to study and design new type of timber structures made mainly of boards and with nailed, screwed or bolted joints (Zamperini 2011). The new mindset formed in the analytical school of steel structures drove engineers to abandon traditional carpentry schemes to seek solutions easier to be analysed. Thanks to slenderness of members and to the simplicity of the joints, they could design these new trusses according to the structural schemes of the steel truss with loads applied in the joints. Hence the structural assessment of these trusses could be done with the theory of statically–determinate trusses (Giordano 1947; Arcangeli 1949).

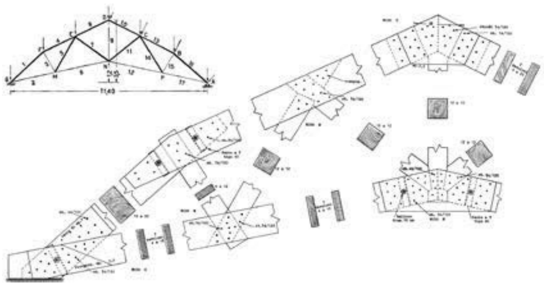

**Fig. 2** Timber truss made of nailed boards[5]

## 5 Conclusion

The evolution path quickly outlined in this paper shows important and almost forgotten events of the history of structural mechanics applied to constructions: after the Second World War, the growing analytical character of structural mechanics and the approximate nature of the methods used for the assessment of timber trusses made them progressively fall into oblivion, and even the more recent historical essays in this field overlook this topic completely.The rediscovery of these events is therefore a key step in the historiographic interpretation of that branch of engineering which is located halfway between theoretical and applied structural mechanics. Furthermore the comprehension of the mindset of the engineers, that designed timber trusses in the nineteenth century and up to the mid–twentieth century, is of fundamental importance in order to fully understand these structures on which today we must intervene for preservation purposes.

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# *Remembering Mauro Francaviglia*

## Marcella Palese and Ekkehart Winterroth

The relevance and worldwide impact of the scientific work of Mauro Francaviglia is very well known.

We want here to recall his ability in communicating science and thus, in particular, his role as scientific guide for us, since we were his PhD students. What was fascinating in being a student of Mauro was his interest for science as a whole, for ideas rather than merely computations.

Mauro was naturally attracted by historical and epistemological problems and his personal interest for beauty in mathematics, for the role of structures and in general of geometric methods and their meaning for physics, has been for his students always inspiring.

As colleagues and collaborators he always encouraged us in exploring new fields, looking for connections between various aspects of a problem, deeply understanding the implications of results.

We will miss his quick grasping the potential of a new idea or point of view, discussions with him, and his friendly attitude.

---

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Pisano R, Capecchi D, Lukešová A (eds) (2013). *Physics, Astronomy and Engineering. Critical Problems in the History of Science and Society. Proceedings of the 32nd International Congress of the Italian Society of Historians of Physics and Astronomy.* The Scientia Socialis Press, Šiauliai. ISBN: 978-609-95513-0-2

# *Remembering Epaminondas Vampoulis*

**Dimitra Giannara**

In the age of 45 years, Epaminondas Vampoulis passed away a few weeks before SISFA congress, where he was expected as a contributor.

He was a significant researcher with a relevant work at the Universities of Patras and Thessaloniki, where he was teaching these last years. His passionate interest for the philosophy of the XVII and XVIII centuries, and especially for the bonds between science and philosophy, gave fruit to many constructive lessons and scientific articles.

His loss leaves a great blankness to the Studies and to Friendship, as he had always been dedicated with passion in his work and he was giving out generously knowledge and guidance.

While God has decided to take him from us so early, he can rest secure in the thought that he has already gained the respect of the scientific community and the warmth in the heart of those fortunate enough to have known him.

Most truly: requiescat in pace, dear Epaminondas.

Dimitra Giannara
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Pisano R, Capecchi D, Lukešová A (eds) (2013). *Physics, Astronomy and Engineering. Critical Problems in the History of Science and Society. Proceedings of the 32nd International Congress of the Italian Society of Historians of Physics and Astronomy.* The Scientia Socialis Press, Šiauliai. ISBN: 978-609-95513-0-2

# Appendix

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# The Venue & Lobby desk

## Venue

Faculty of Engineering
University of Roma La Sapienza, Via Eudossiana, 18, Roma, Italy


**Google Map © – SISFA 2012 Congress Venue Map View**

## Congress' Sites & Facilities

Events at *Chiostro*, Faculty of Engineering, University of Roma , La Sapienza

**Welcome Lobby & Help Desk**
Daily 3–days Congress, *Faculty of Engineering*

**Thursday, 27 September 2012**
Plenary *Sala del Chiostro* (200 s.) Room*, Faculty of Engineering*
*Sala degli Affreschi* (60 s.) Room*, Faculty of Engineering*
8.30 am – 11.00 pm

**Thursday, 27 September 2012**
*Concert for Two Violins* & *"General Faraday" lecture*
*Chiostro Area, Faculty of Engineering*
From 8.30 pm

**Friday, 28 September 2012**
*Plenary Room 1* (200 s.), *Faculty of Engineering*
*Sala degli Affreschi* (60 s.) Room, *Faculty of Engineering*
8.30 am – 8.15 pm

**Friday, 28 September 2012**
*Plenary Room 1* (200 s.): General SISFA Assembly, *Faculty of Engineering*
6.40 pm – 7.45 pm

**Thursday and Friday, 27–28 September 2012**
*Ancient and Rare Books Exhibition*
*Chiostro Area, Faculty of Engineering*

**Thursday and Friday, 27 September 2012**
*Ancient and Rare Measurements Instruments Exhibition*
*Faculty of Engineering*

Events at *Sala degli Affreschi*.
A particular of the "Pozzo" at *Chiostro* (fl. early 500, attributed to Giuliano da Sangallo's tradition) with coat of the Della Rovere and Sisto IV and Giulio II' names, Faculty of Engineering University of Roma , La Sapienza

**Saturday, 29 September 2012**
*Sala degli Affreschi* (60 s.) Room, *Faculty of Engineering*
8.00 am – 1.30 pm

**Congress dinner**, **Friday, 28 September 2012 h. 9.00 pm**
*Taverna Urbana* Restaurant

## Chairpersons & International Committees

## Chairpersons of the SISFA 2012 Congress

Danilo Capecchi (Italy)
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Salvo D'Agostino (University of Roma La Sapienza, Italy)

[1] Alphabetical name order.

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Salvatore Esposito (I.N.F.N. sezione di Napoli, Italy)

## International Key–Note Scholars

### Plenary Speakers

Walter NOLL (1925, Germany)
*The Department of Mathematical Sciences*, Carnegie Mellon University
United States of America

*Emeritus professor of mathematics at Carnegie Mellon University, Noll has served as several scientific communities and numerous article, books on mathematics, thermodynamics and history of foundations of science. He also was visiting professor at eminent universities such as Johns Hopkins University, University of Karlsruhe, Israel Institute of Technology, Ecole Polytechnique in Nancy, University of Pisa, the University of Pavia, and Oxford University. For his exceptional and distinguished career he received many honorary achievements such as "The Mathematical World of Walter Noll"* (*Springer–Verlag*, 1996). *He is best known for developing mathematical tools of classical mechanics and thermodynamics. His work concerns mostly with the conceptual foundations of some branches of pure mathematics and also of the mathematics that underlies some physical theories, in particular classical continuum mechanics and thermodynamics as well as special relativity. Since 60's he is the main specialist of "Non–Linear Field Theories of Mechanics". He was the first Ph.D. student of Clifford Ambrose Truesdell* (1919–2000) *and later was also co–author with him in many mathematical foundations researches which became the standard reference work in the field. His works are translated and reprinted in several languages, into Chinese, too.*

Jean DHOMBRES (1942, France)
*The Centre Alexandre Koyré–CNRS*, *Ecole des Hautes Etudes en Sciences Sociale,* Paris
France

*Jean Dhombres* is *Directeur d'études at Ecole des Hautes Etudes en Sciences Sociale, Paris, Directeur de recherche et professeur émérite at Centre National de la Recherche Scientifique (CNRS). Professor at University of Nantes, later was appointed as Directeur d'études at Ecole des Hautes Etudes en Sciences Sociale, Paris. His research concerns both mathematical aspects on functional analysis and equations, and features regarding history of mathematics: institutions (Ecole polytechnique, Ecole Normale, Académie des Sciences, Expédition d'Egypte), cultural aspects (from Révolution to Restauration, baroque science, etc..), concepts (relative numbers, theory of proportions, concept of function, equations etc..), biographies (Fourier, Lazare Carnot, de Saint–Vincent, Gergonne), books (leçons de l'École normale de l'an III). He is author of distinguished works concerning Leçons sur le calcul différentiel et le calcul intégral by Jean Bernoulli, l'Analyse des Infiniment petits by de l'Hôpital, Integer calculus by Jean Bernoulli (Opera omnia).*

Marco CECCARELLI (1958, Italy)
*The Dipartimento di Ingegneria Civile e Meccanica*, University of Cassino and South Latium, Italy

*Marco Ceccarelli obtained four Honoris Causa Doctor Degrees in Engineering from National University of Lima, Perù, Technical University of Kursk, Russia, Technical University of Brasov, Romania and from University of Craiova, Romania, for his academic and scientific career, and his support to the academic activity. He is an ASME fellow and IFToMM past President. He is professor of mechanics of machines and mechanisms, and director of the Laboratory of Robotics and Mechatronics (LARM) at Cassino University. In the field of history of science he has carried out a pioneering activity in addressing attention to the History of Mechanical Engineering from technical viewpoints. This activity has attracted great interest within the worldwide IFToMM community (International Federation for the Promotion of Mechanism and Machine Science) and collaboration with historians from the traditional community of history of science, by organizing symposia and workshops and by chairing the Springer book series on History of Machine and Mechanism Science. Particularly, he carries out researches on historical developments of mechanism and machine Science, such as machines, mechanisms, kinematics, and design methods, beside working on Robotics and Mechanism Design.*

Peter HEERING (1961, Germany)
*The Institute of Physics and Chemistry and its Didactics*, University of Flensburg
Germany

*Peter Heering is professor of physics and physics didactics at the University Flensburg since 2009. He was trained at the University Oldenburg where he completed his Ph.D. in 1995. In 2006 he completed his habilitation in history of science. Between 1996 and 2009 he was senior lecturer at the physics institute of the University Oldenburg. In 2004, he was Scholar–in–Residence at the Deutsches Museum Munich, in 2006/7 he was professorial substitute of the chair for physics didactics at the University Augsburg. His main research interests are historical scientific practices, which he analyses with the replication method, the relation between research and teaching experiments and the implementation of history of science in science education. He is currently President–elect of the IHPST–Group (http://ihpst.net/) and Vice–President of the Inter–divisional Teaching Commission of the International Union of History and Philosophy of Science.*

Frank A.J.L. JAMES (1955, U.K.)
*The Royal Institution of Great Britain*
United Kingdom

*Frank A.J.L. James* is *professor of the History of Science at The Royal Institution of Great Britain. He has written widely on science and technology in the nineteenth century and how they relate to other areas of society and culture, for example technology, art, religion and the military. He is particularly interested in the processes by which knowledge created in a laboratory is applied in practical situations, an area where the Royal Institution played an enormously significant role. He is editor of the Correspondence Michael Faraday (now complete in six volumes). He is Past President of the Newcomen Society for the History of Engineering and Technology and is Past President of the British Society for the History of Science. He is the chair of the National Organising Committee for the 24th International Congress for the History of Science and Technology to be held in Manchester in July 2013).*

Radim KOČANDRLE (1975, Czech Republic)
*Research Centre for Theory and History of Science*,
University of West Bohemia in Pilsen
Czech Republic

*Radim Kočandrle is assistant professor at the department of Philosophy, Faculty of Philosophy and Arts, University of West Bohemia in Pilsen, Czech Republic. He works on ancient history–philosophy of cosmology mainly focused on the Presocratics period. Kočandrle is one of the main member of the Research Centre for Theory and History of Science. His historical and philosophical main interests are largely published concerning history and cosmology of science on Anaximander of Miletus*, *Physis of the Ionian thinkers, early map of the Ancient world.*

## Invited Guest Physics Lecture on Higgs Boson

Aleandro NISATI (1959, Italy)
*I.N.F.N. Sezione di Roma–CERN*, Italy–Switzerland
Italy–Switzerland

*Alenadro Nisati is I.N.F.N. (The Italian Institute of Nuclear Physics) physicist researcher and scientific associate at CERN on LHC (Large Hadron Collider), Geneva: origin of the electroweak symmetry breaking, as well as the search of new physics beyond the Standard Model. His research regards with new and strange particles producing a large publishing–and–spreading–job within the ECFA (The European Committee for Future Accelerators) particularly on Higgs searches, as well as studies of muon production, in proton–proton collisions at the LHC. He is one of the main founding physicists of one of the two main experiments at LHC, A Toroidal LHC ApparatuS (ATLAS) where he is Physics Experimental Coordinator: scientific program and the project on muon detection and spectrometer, trigger system. Nisati also designed the first–level muon trigger algorithm, as well as the one of the second–level and for that he was elected chair of the Trigger/DAQ Institutes Board until 2007, and Higgs group co–convener for next two years. Recently (2012) he is also coordinator of the "ATLAS Input to the European Strategy Preparatory Group" and candidate as Spokeperson of the experiment. ATLAS (and CMS, the main experiments at LHC) has found in summer 2012 a strong evidence of the production at the LHC of a new boson with mass near 126 GeV. This new particle is consistent, within the current available experimental accuracy, with the Standard Model Higgs boson.*

## Invited Talks[2]

Agamenon Rodrigues Oliveira (Polytechnic School of Rio de Janeiro, Federal University of Rio de Janeiro, Brazil)
Daniel Špelda (Research Centre for Theory and History of Science, University of West Bohemia in Pilsen, Czech Republic)
Liliane Alfonsi (Laboratoire Groupe d'Histoire et de Diffusion des Sciences d'Orsay, Université Paris–Sud, Orsay, France)
Mauro Francaviglia (Italian Society of General Relativity, University of Torino, Italy)
Michela Cigola (Dipartimento di Ingegneria Civile e Meccanica, University of Cassino, Italy)
Salvatore Esposito (I.N.F.N. – Sezione di Napoli, Italy)
Steffen Ducheyne (Centre for Logic and Philosophy of Science, Free University of Brussels, Belgium)
Young Suh Kim (Center for Fundamental Physics, University of Maryland, U.S.A.)

## Chairpersons of the Sessions[3]

Anna Lukešová (Research Centre for Theory and History of Science, University of West Bohemia in Pilsen, Czech Republic)
Antonio di Meo (Faculty of Philosophy, University of Roma La Sapienza, Italy)
Arcangelo Rossi (Dipartimento di Fisica, University of Lecce, Italy)
Danilo Capecchi (Dipartimento di Ingegneria Strutturale e Geotecnica, University of Roma La Sapienza, Italy)
Flavia Marcacci (Dipartimento di Scienze di Base e Fondamenti, University of Urbino/Faculty of Philosophy, Pontifical Lateran University, Italy)
Giuseppe Ruta (Dipartimento di Ingegneria Strutturale e Geotecnica, University of Roma La Sapienza, Italy)

[2] Alphabetical name order.
[3] *Ibidem*.

Liliane Alfonsi (Laboratoire Groupe d'Histoire et de Diffusion des Sciences d'Orsay, Université Paris–Sud, Orsay, France)
Ludmila Dostálová (Research Centre for Theory and History of Science, University of West Bohemia in Pilsen, Czech Republic)
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Massimo Mazzoni (Osservatorio Astronomico di Arcetri, University of Firenze, Italy)
Raffaele Pisano (SCité, University of Lille 1, France/RCTHS, University of West Bohemia, Czech Republic)
Roberto Mantovani (Physics Laboratory Urbino Museum of Science and Technology, University of Urbino, Italy)
Salvatore Esposito (I.N.F.N. – Sezione di Napoli, Italy)
Salvo D'Agostino (Dipartimento di fisica, University of Roma La Sapienza, Italy)
Steffen Ducheyne (Centre for Logic and Philosophy of Science, Free University of Brussels, Belgium)
Young S. Kim (Center for Fundamental Physics, University of Maryland, U.S.A.)

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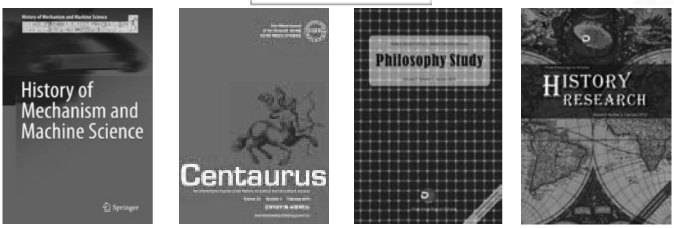



*Springer*
*The Netherlands*

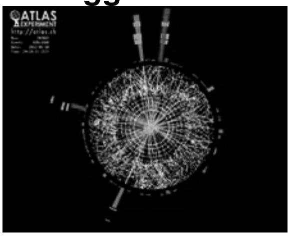

*Ancient and Rare books exhibition*

*Springer–Verlag*
*Italy*

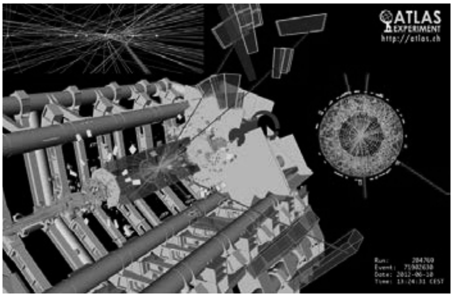

*Official Catering Congress*

# Special Event on Higgs Boson Discovery

## Invited Guest Physics Lecture on Higgs Boson[4]




Candidate Higgs decay to four electrons re-




Higgs Decay to four muons recorded by ATLAS in 2012

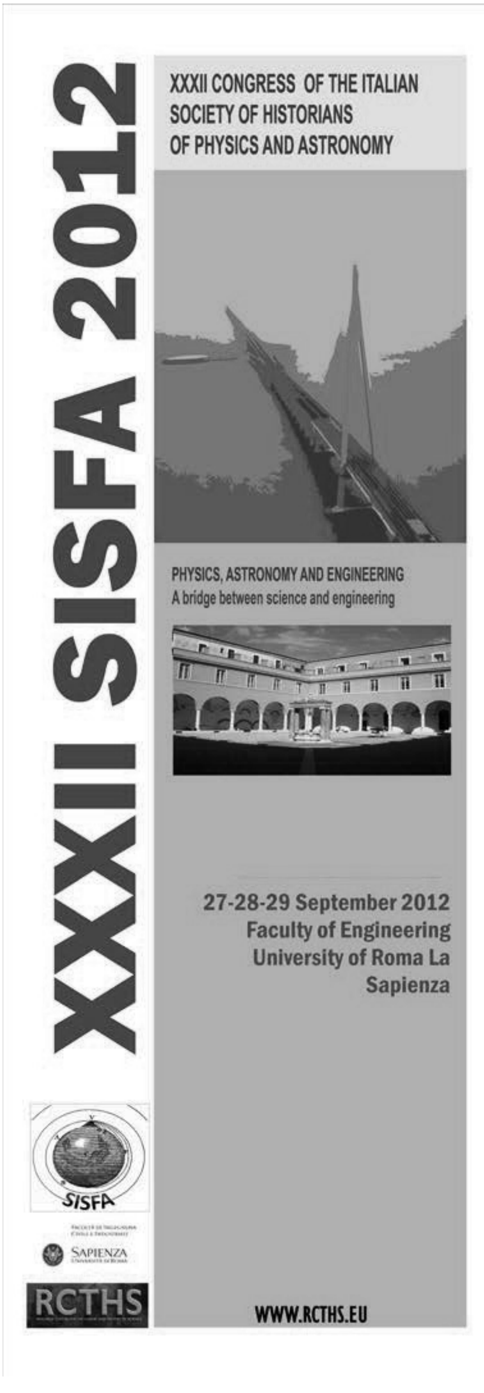
ATLAS EXPERIMENT

2012, 27 September h. 11.45–12.15 am

Invited Guest Physics Lecture
Aleandro NISATI (*I.N.F.N. Sezione di Roma–CERN*, Italy/Switzerland)
*Search of the Higgs boson at the Large Hadron Collider.*
On 4 July 2012, the *ATLAS* experiment presented a preview of its updated results on the search for the Higgs Boson. The results were shown at a seminar held jointly at *CERN* and via video link at *ICHEP*, the International Conference for High Energy Physics in Melbourne, Australia. At *CERN*, preliminary results were presented to scientists on site and via webcast to their colleagues located in hundreds of institutions around the world. Aleandro Nisati is *ATLAS Physics coordinator.*

[4] Images credit: http://www.atlas.ch/news/2012/latest-results-from-higgs-search.html

## Posters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XXXII CONGRESS OF THE ITALIAN
SOCIETY OF HISTORIANS
OF PHYSICS AND ASTRONOMY
PHYSICS, ASTRONOMY AND ENGINEERING
A bridge between science and engineering
27-28-29 September 2012
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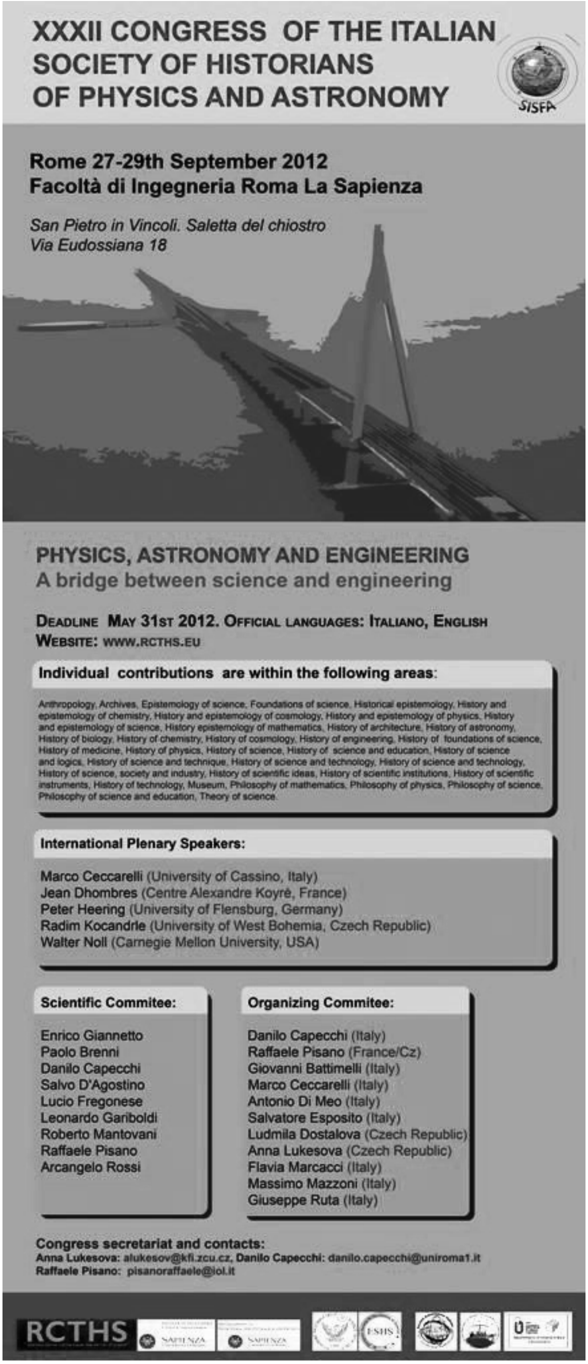
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A bridge between science and engineering
DEADLINE MAY 31ST 2012. OFFICIAL LANGUAGES: ITALIANO, ENGLISH
WEBSITE: WWW.RCTHS.EU
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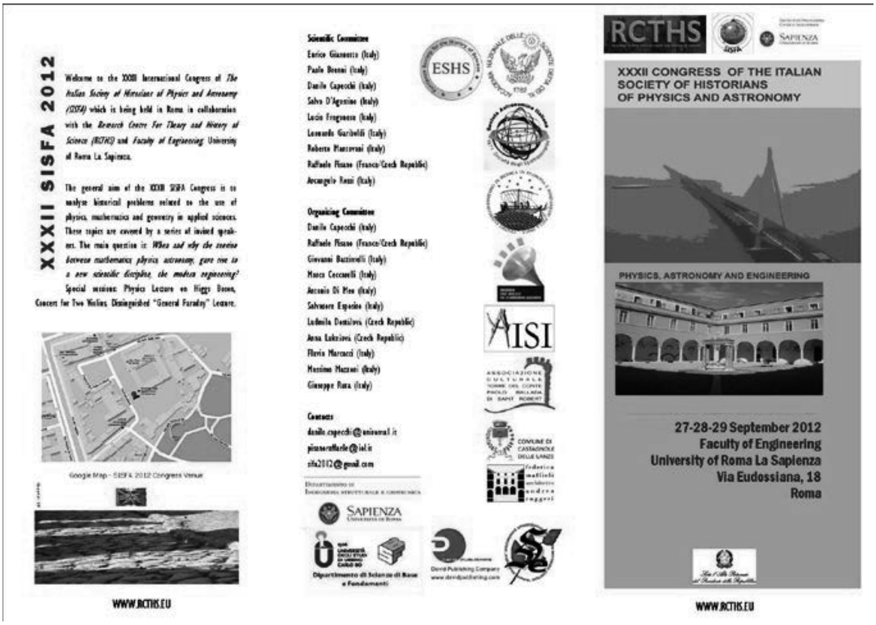

XXXII SISFA 2012

Welcome to the XXXII International Congress of *The Italian Society of Historians of Physics and Astronomy (SISFA)* which is being held in Roma in collaboration with the *Research Centre For Theory and History of Science (RCTHS)* and *Faculty of Engineering* University of Roma La Sapienza.

The general aim of the XXXII SISFA Congress is to analyze historical problems related to the use of physics, mathematics and geometry in applied sciences. These topics are covered by a series of invited speakers. The main question is: *When and why the interplay between mathematics physics, astronomy, gave rise to a new scientific discipline, the modern engineering?* Special sessions: Physics Lecture on Higgs Boson, Concert for Two Violins, Distinguished "General Faraday" Lecture.

Google Map - SISFA 2012 Congress Venue

WWW.RCTHS.EU

**Scientific Committee**
Enrico Giannetto (Italy)
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27-28-29 September 2012
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Via Eudossiana, 18
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**am — Thursday 27, 2012**

8.30-daily — *Welcome Congress (Anna Lukešová) & helpdesk reception*

9.00-9.25, *Sala del Chiostro room* — *Opening Act*. Chairs: Danilo Capecchi & Raffaele Pisano. Fabrizio Vestroni, Dean of the Faculty of Engineering La Sapienza

9.30-10.15 — **Plenary Speaker: Jean Dhombres (F)**. *Conflicting issues for mathematics at the Ecole polytechnique during its first forty years of existence: the role of Lazare Carnot between Monge and Laplace*. Chair: Raffaele Pisano Ruta (F/Cz)

10.30-10.40 — *Coffee break*

10.45-11.30 — **Plenary Speaker: Walter Noll (U.S.A.)**. *Physics and Mathematics without Coordinates*. Chair: Giuseppe Ruta (I)

11.45-12.15 — **Invited Guest Physics Lecture on Higgs Boson: Alessandro Nisati (I/CH)**. *Search of the Higgs boson at the Large Hadron Collider*. Chair: Salvo D'Agostino (I)

12.30-1.00 — **Invited Talk: Agamenon R. Oliveira (Br)**. *The Role of the Concept of Work in the Development of Applied Mechanics*. Chair: Marco Ceccarelli (I)

1.00-1.45 — *Lunch break*

pm 2.00-5.05, *Sala del Chiostro room* — **Invited Talk: Mauro Francaviglia (I)**. *"Palatini's Method" Offers a New View to Non-Euclidean Geometry*. Chair: Flavia Marcacci (I). 7 Contributes Sessions

5.05-5.15 — *Coffee break*

*Two Parallel Contributes Sessions*

5.15-7.45, *Sala del Chiostro room* — **Invited Talk and Chair: Salvatore Esposito (I)**. *Spreading Scientific Philosophies with Instruments: The Case of Atwood's Machine*. 5 Contributes Sessions

5.15-7.45, *Sala degli Affreschi room* — **Invited Talk and Chair: Steffen Ducheyne (Be)**. *Reassessing W. J.'s Gravesande's appropriation of Newton's methodology*. 6 Contributes Sessions

*Special Event: Concert & Evening Plenary*

8.30 — **Claudio Buccarella & Giulia Capecchi (I)** *(Conservatory St Cecilia, Roma): Concert for Two Violins*

9.00, *Closing Thursday session* — **"General Faraday Lecture": Frank A.J.L. James (U.K.)**

**am — Friday 28, 2012**

8.30-daily — *Welcome Congress (Anna Lukešová) & helpdesk reception*

8.30-9.15, *Plenary room 1* — **Plenary Speaker: Radim Kočandrle (Cz)**. *The Earth Floats Unsupported in Space*. Chair: Ludmila Dostalová (Czech Republic)

9.30-10.15 — **Plenary Speaker: Marco Ceccarelli (I)**. *An Outline of History of Mechanism Design in Servicing Science*. Chair: Danilo Capecchi (Italy)

10.30-10.40 — *Coffee break*

10.45-12.55 — **Invited Talk and Chair: Young S. Kim (U.S.A.)**. *Historical Approach to Physics according to Kant, Einstein, and Hegel*. 8 Contributes Sessions

1.00-1.45 — *Lunch break*

1.46-1.59 — *Photo SISFA 2012 Session: Chiostro*

pm — *Two Parallel Contributes Sessions*

2.00-4.25, *Sala degli Affreschi room* — **Invited Talk and Chair: Liliana Alfonsi (F)**. *A turning point in French officers training: Mechanics in the mathematics course of Étienne Bézout (1730–1783)*. 5 Contributes Sessions

2.00-4.25, *Plenary room 1* — **Invited Talk: Daniel Špelda (Cz)**. *Early modern histories of astronomy: On searching for antediluvian astronomy and vision of astronomical progress*. Chair: Massimo Mazzoni (I). 6 Contributes Sessions

4.30-4.40 — *Coffee break*

4.45-6.05, *Sala degli Affreschi room* — **(continued) Chair: Liliana Alfonsi (F)**. 4 Contributes Sessions

4.45-6.05, *Plenary room 1* — **(continued) Chair: Massimo Mazzoni (I)**. 4 Contributes Sessions

*Special Event: D'Agostino Tribute Session*

6.05-6.40, *Plenary room 1* — **Chair: Arcangelo Rossi (I)**. Stefano Bordoni (I): *Salvo D'Agostino Physics and History. Tradition And Innovation*. Salvo D'Agostino (I): *Reply*. *Free Debate*: Rossi (I), Bevilacqua (I)

6.40-7.45, *Plenary room 1* — **General SISFA Assembly**

9.00, *Closing Friday session* — **Congress Dinner: *Taverna Urbana* Restaurant**. http://www.ristorantetavernaurbana.com. Via Urbana 137, Roma. Tel: +39 06-4884439

**am — Saturday 29, 2012**

8.00-1.00 — *Welcome Congress (Anna Lukešová) & helpdesk reception*

8.00-8.45, *Sala degli Affreschi room* — **Plenary Speaker: Peter Heering (D)**. *The analysis of Historical Experiments with the Replication Method*. Chair: Roberto Mantovani (I)

9.00-10.20, *Sala degli Affreschi room* — Chair: Antonio Di Meo (I). 4 Contributes Session

10.30-10.40 — *Coffee break*

10.40-11.10, *Sala degli Affreschi room* — **Invited Talk: Michela Cigola (I)**. *The Qiqi tushuo by the jesuit Johann Schreck: european Theatra Machinarum in China in the XVIIth century*. Chair: Anna Lukešová (Cz)

11.15-12.50, *Sala degli Affreschi room* — Chair: Danilo Capecchi (I). 7 Contributes Session

1.15-1.30, *Sala degli Affreschi room* — *Closing Saturday session*. Chairs: Danilo Capecchi and Raffaele Pisano. *Closing Congress Acts – Organizing Committee*

1.30 — *Free Lunch or Greetings. No others planned activities*

**Permanent Events Involved:**

**Thursday and Friday, 27–28 September 2012**
*Ancient and Rare Books Exhibition, Library "C. Beaga"*, Chiostro Area, Faculty of Engineering

**Thursday and Friday, 27 September 2012**
*Private Collection of Ancient and Rare Measurements Instruments Exhibition by Antonio Salmeri (The Italian Society for History of Mathematics) and Marcello Salmeri (University of Roma 2 Tor Vergata)*, Faculty of Engineering

**Permanent during the 3-days congress**
*Posters Panel Session is provided by some SISFA 2012 participants*. Faculty of Engineering

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Registration and submissions:

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Dipartimento di Ingegneria strutturale e geotecnica
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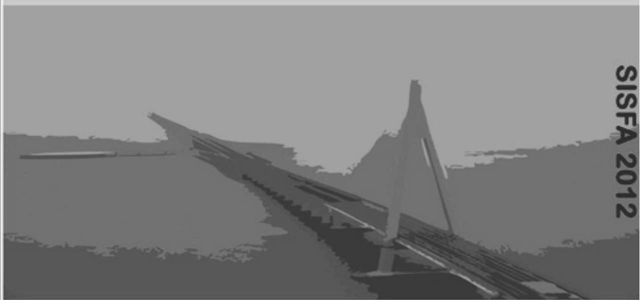


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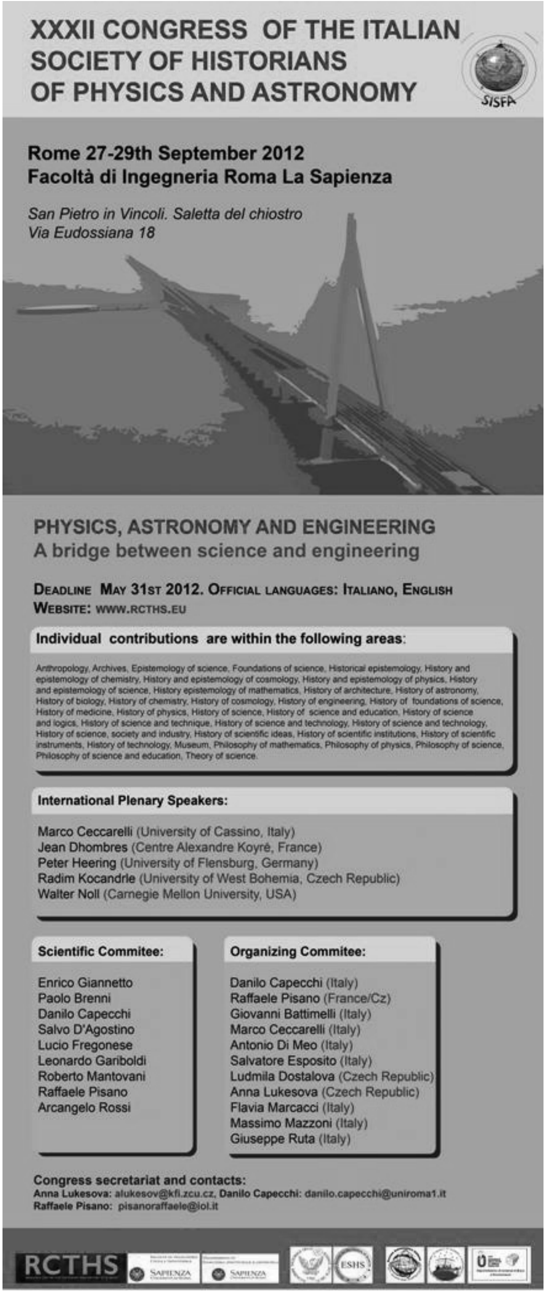
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## GIOVANNI BOAGA CENTRAL LIBRARY

The Central Library Giovanni Boaga was built in 1873 as the library of the School of Application for Engineers in Rome, but it already existed since 1817, when Pope Pius VII established the School of Engineering.
The founder of the library was Valentino Cerruti. His highly educated and enlightened mind, in all branches of pure and applied mathematics, was able to give the library an address of such magnitude to make it the main library of its kind in Italy. He held the direction until his appointment as Director of the School forced him to leave. Lucio Silla, his assistant for the teaching of rational mechanics succeeded him. Prof. Anastasi Anastasio followed, who held the direction of the library in the academic year 1921-22, but who had to leave for other assignments. It was the turn of Vittorugo Foschi. Currently the Central Library is dedicated to Giovanni Boaga, a distinguished mathematician.
The library was renovated in 1976 while Giovanni Sibeni was director of the Library, from 1970 to 2000. The restructuring is due to the efforts of Enrico Mandolesi which included modern elements in the original structure, keeping the gallery and the antique portal of the Library of the Lateran Canons of St. Peter in Chains, dating back to 1768 and moved to its present site in 1938.

LIBRARY SERVICES
- A reading room with 220 seats;
- A multimedia room equipped with 8 computers connected to Internet
- Sapienza's wireless network
- 28000 modern textbooks
- 710 old books (published until 1830)
- 1090 journal titles
- online access to Sapienza's data bases, journals and e-books

SAPIENZA'S LIBRARY SYSTEM

The Library System of Sapienza, established by rector ordinance No. 4461 of 15.12.2011, aims to ensure the conservation, development, enhancement and integrated management of the entire bibliographic and documentary heritage of Sapienza University and access to online information resources according to the needs of research, teaching and administration. It aims to ensure high standards of effectiveness and efficiency of the organization and operation of services and library networks and periodically checks the degree of user satisfaction.

GIOVANNI BOAGA LIBRARY- SISFA 2012

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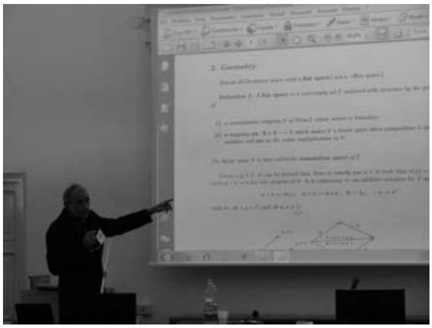
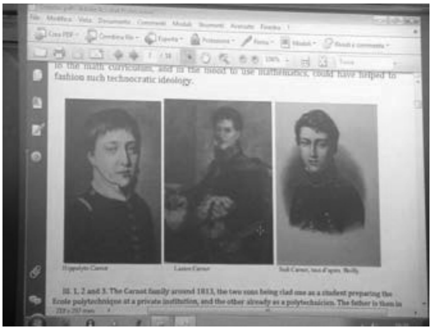
## Some Images during the Event in Roma




SISFA 2012
The Role of the Concept of
Work in the Development
of Applied Mechanics


fashion such technocratic ideology.


Hippolyte Carnot


The ATLAS and CMS detectors


130 140 150 160 170 180 190 200


The Standard Model


Ri
The Royal Institution


Modello di abaco russo
Questo abaco
è rimasto in uso nei negozi
dell'Unione Sovietica


Regolo cilindrico
Questo regolo
(di grande rarità)
Veniva utilizzato per il calcolo
dei numeri complessi


Regolo calcolatore "Charpenter"
Rarissimo esemplare
in bronzo e ottone

# Index

Pisano R, Capecchi D, Lukešová A (eds) (2013). *Physics, Astronomy and Engineering. Critical Problems in the History of Science and Society. Proceedings of the 32nd International Congress of the Italian Society of Historians of Physics and Astronomy.* The Scientia Socialis Press, Šiauliai. ISBN: 978-609-95513-0-2

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Raffaele Pisano • Danilo Capecchi • Anna Lukešová
*Editors*
Physics, Astronomy and Engineering. Critical Problems in the History of Science and Society.
*International 32nd Congress of the Italian Society of Historians of Physics and Astronomy SISFA 2012*

This book presents the Proceedings of 32nd International Congress of the *Italian Society of Historians of Physics and Astronomy* (SISFA) held in Roma on 2012, 27th–29th September (more than 80 participants from 11 countries). It was mainly organized in collaboration with the *Faculty of Engineering*, University of Roma La Sapienza, Italy, the *Research Centre for Theory and History of Scienc*e (RCTHS), University of West Bohemia in Pilsen, Czech Republic. The International Proceedings SISFA 2012 represents the historical current state of the art of offering new perspectives in history of physics, astronomy, engineering, sciences & societies and related epistemological and philosophical disciplines.

The authors explained the various ways in which sciences worked in the past. Particularly distinguished scholars like Walter Noll (*Carnegie Mellon University*, U.S.A), Jean Dhombres (*CNRS–École des Hautes Etudes en Sciences Sociale*, France), Aleandro Nisati (*CERN*, CH) and a special *Foreword* by Chris Bissell (*Open University*, U.K.) helped to create the volume for absorbing reading.

Raffaele Pisano (France) is Lecturer–Researcher of *History of physics, History and epistemology of science,* and *Science & society studies* at the *Sciences, sociétés, cultures dans leurs évolutions*, University of Lille 1, France; head of the *Research Centre for the Theory and History of Science*, University of West Bohemia in Pilsen, Czech Republic. Recently: *Lazare and Sadi Carnot. A Scientific and Filial Relationship* (2013, Netherland: Springer) with Charles Coulston Gillispie, Princeton University.

Danilo Capecchi (Italy) is Professor of *Structural Mechanics* and *History of science* at the Faculty of Architecture, University of Roma la Sapienza, Italy. Recently: *History of Virtual Works Laws. A History of Mechanics Prospective* (2012, Italy: Springer–Verlag– Birkhäuser).

Anna Lukešová (Czech Republic) is Ph.D. Candidate at the *Department of Philosophy* and member of the *Research Centre for Theory and History of Science*, University of West Bohemia in Pilsen, Czech Republic.

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