Chapter 2
The Conceptual Basis to Work Studies

"**Socrates**—Can it be, then, that Protagoras was a very ingenious person who threw out this dark saying for the benefit of the common herd like ourselves, and reserved the truth as a secret doctrine to be revealed to his disciples?

Theaetetus—What do you mean by that, Socrates?

Socrates—I will tell you; and indeed the doctrine is a remarkable one. It declares that nothing is *one* thing just by itself, nor can you rightly call it by some definite name, nor even say it is of any definite sort. On the contrary, if you call it *large*, it will be found to be small; if *heavy,* to be also light; and so on all through, because nothing is *one* thing or *some* thing or of any definite sort. All the things we are pleased to say *are,* really are in process of becoming, as a result of movement and change and of blending one with another…"

(Plato's Theory of Knowledge—The Theaetetus and the Sophist—Translated by Francis M. Cornford—p. 36, Dover Publications, New York, 2003)

2.1 Historical Character of Physical Concepts Construction

In his paper: The historical character of adequacy of mathematics to physics, Michel Paty[1] wrote: "Following through history of sciences, several remarkable cases of relations between physics and mathematics, we realized that the capacity of mathematics formalism to express in an appropriate and fruitful manner the physical problems, is not a fact of universal and extemporal nature. It is the result, in each time, and to each new studied problem, a construction, that put in action the "system" of the mathematics and physics of this time and the nature of the concepts and physical quantities involved."

By analyzing this chapter with respect to a conceptual framework in which the concept of work is supported, we made an initial decomposition of the elements

[1] Michel Paty specifically treats the problem of mathematics' adequacy to physics in two papers (Paty 1991, 1999). See also Petitot in (Petitot 1990).

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of work, complemented by a historical perspective in a similar way made by Paty as cited above, meaning that the concepts of physics and the utilization of mathematics in so fruitful form belong to a common mathematical-physical construction of historical character. In addition, one also may conclude that it is necessary for each particular physics' problem to mobilize all available mathematical tools, or, if necessary, to develop it. However, one recognizes that there is a fundamental constitutive aspect of mathematics with respect to the representation of the physical world that is a more intrinsic indication of the participation of mathematics in it.

Obviously, this conclusion is not so explicit from the citation, but one can conclude this from a reading of the text. It means that mathematics is not a mere language used for representing reality or to operate symbolically, as some authors postulate. In other words, mathematics belongs to a concept's construction, although the citation also emphasizes that there is a kind of symbiosis between mathematics and physics and that it is not a general or universal fact independent of the physical problem under consideration. This would be equivalent to considering mathematics as a tool ever available to physics, which is not true. What, in fact, happens is a complex relationship of a common construction in both fields but historically conditioned.

The utilization and adequacy of mathematics as a better form of representation of the physical world are appropriate in well-defined moments, historically dated and also referring to precise theories and forms as well as to defined types of physical problems.[2] Particular to the field of Rational mechanics, for example, it is well known that mechanical laws have profited significantly from the invention of differential and integral calculus developed some years before by Newton and in an independent form by Leibniz.

The formulation of fluxions calculus by Newton, as a result of his achievements in infinite series, is simultaneously the study of the motion problem of bodies considered according to geometrical methods which also led to a new branch of mathematics (Newton 1994). Newton was aware of how physics influenced the construction of mathematical concepts when he stated in the preface of the first edition of *Principia*: *Geometry is founded on mechanical practice, and is this part of universal mechanics that postulates and demonstrates exactly the art of measurement* (Newton 2002).

In order to corroborate the above statement, Michel Paty also considers that the foundation of calculus invented by Newton in 1666 uses mathematical quantities that are generated by a continuous motion which opposes concepts of infinitesimal quantities. Indeed, Newton does not directly use differential calculus in his mechanics, especially in the derivation of his second law of motion, which would be done some years after by Leonhard Euler. The Swiss mathematician formulated the mathematical expression of Newton's second law in 1752.[3]

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[2] Michel Paty in (Paty 1991) presents some examples of mathematical constructions of physical concepts in two fields: classical mechanics and the theory of relativity.

[3] Euler, in *The Discovery of a New Principle of Mechanics*, published in 1752, presents the differential equations expressing Newton´s second law. Later on, he called these equations *the first principles of mechanics* (Truesdell 1983).

Again, Paty emphasizes that Newton remarks in his *first and last reasons*, which open book I, *The bodies' motion,* are quite similar to what is found in the calculus of fluxions. He wrote: "The conceptualization of fluxions—without the symbolism—penetrates in some way this geometry transforming it in relation to mechanics, what will be translated in an evident manner by the use of differential symbolism (Paty 1991)". In other words, the absence (explicit) of calculus in Newtonian mechanics is not a complete truth and represents a more complex process which Michel Paty realizes and remarks upon with great perspicacity.

The formalization of mechanics which begins with Pierre Varignon and d'Alembert, as we will see later on, continues with Euler and has its crowning with Lagrange; it will be presented in detail in Chap. 4. Besides these important names, Jacques and Jean Bernoulli developed and applied this new methodology to mechanics.

In fact, this period is very rich in the construction of basic mechanical concepts and illustrates practically what was discussed above concerning the relation between mathematics and representation of the physical world. However, only with the generation of mathematicians of d'Alembert and Euler, but incorporating Daniel Bernoulli, Alexis Clairaut and others, can we say that the universalization of differential and integral calculus has happened. This fruitful process opens multiple possibilities for the development of mechanics and astronomy, mainly, exploring Newton's system of the world beyond the limits of the studies of bodies' motion. The way adopted by Lagrange via mathematical analysis led him to the great mechanics' formalization in 1788 with his *Analytical Mechanics*.

Michel Blay, in his *La Naissance de la Mécanique Analytique* (Blay 1992), made an analysis similar to our previous description concerning mechanical development with the creation of differential and integral calculus, also with respect to the role of mathematics in the description of the physical world. Thus, he states: "The comparison between leibnizians and varignonnians methods in the second part, has shown us clearly that the differential conceptualization of the science of motion cannot be interpreted as result of a mere transposition in differential terms, of the concepts and view points of the science of motion such that it was expressed previously, but as the result of a true conceptual reconstruction that has led to a reorganization of the science of motion field around the concepts of instantaneous velocity and acceleratrix force."

He remarks the following about the relationship between mathematics and physics: "From a general point of view, the conceptual varignonnian work testifies that mathematics and physics have a constitutive relationship, or better, a constituent relationship, because by analyzing this work, in the dynamics of this relation—one can say also about its interaction—that they are intrinsically related to the new concepts, in the occurrence here, of the instantaneous velocity and acceleratrix force".

Another important aspect highlighting the historical character of the formation of concepts to the construction of theories, mainly those concerning the physical world, is technological development. As we know, concepts and theories must demonstrate their explanatory capacity as well as their fruitfulness facing the facts (phenomena) with respect to the physical world. Therefore, they need experimental validation, which only happens after a long process of improvement of the tools and experimental techniques used. As an example, we can use the restricted theory of relativity that arose after experimental demonstration of the constancy of light velocity related to any system of reference. This fact implied a reconstruction of mechanical theory with serious consequences for ether theory that became cumbersome in spite of resistance.

An example of how an experimental apparatus interferes with theories representing reality comes from models of matter constitution,[4] which need sophisticated particle accelerators, as well as very specialized computational technologies. From the informatics point of view, the use of computers in physical studies has introduced a conceptual revolution. It was possible also to discover unknown aspects of the behavior of systems, such as chaotic behavior in deterministic systems (Prigogine 1996) transforming classical mechanics into a modern tool for system analysis. As a consequence of these modifications, several new concepts have arisen: fractals, strange attractors, complexity phenomena (Nussenzveig 1999) and a new branch of geometry with non-integer dimensions. However, besides the new concepts, some new scientific disciplines have also appeared: graphics computation, artificial intelligence, etc. On the other hand, these new tools create favorable conditions for new discovery. Finally, it is worth noting, as we said in the first chapter about the theory of knowledge, that men historically construct their tools to explore nature and that our approach to reality is progressive, neither continuously nor linearly, but with the rhythm dictated by the capacity to construct these tools.

By analyzing the evolution of physical concepts, one observes that they are historically conditioned to technological development, so obviously it is not the unique factor. This evolution also depends upon the development of other concepts and theories that in some cases have a crucial importance to the progress of physics. One can remark that mechanical theory has known a fruitful development after the application of differential and integral calculus. Calculus' formalism has made the manipulation of algebraic problems, primarily those after Euler, much easier. The success of this mathematization has induced a very fruitful mathematization in other particular sciences, such as heat, electricity, magnetism, optics, etc., in spite of the failure of the Laplacian project to extend the Newtonian model of gravitational theory to the other sciences.

The basic concepts or elementary concepts for studying the concept of work had a historical development. This is the objective of the following sections.

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[4] The experiments with modern particle accelerators can explore scales up to 10^{-18} m. A new accelerator is now in operation, the LHC (Large Hadron Collider). It was built by CERN (European Organization for Nuclear Research) from 1998 to 2008, and is the largest and highest-energy particle accelerator to date, with the objective of testing the predictions of different theories of particle physics and high-energy physics, particularly for the existence of the hypothesized Higgs boson and the large family of new particles predicted by supersymmetry (Special edition of Scientific American 2005; D'Espagnat and Klein 1993).

2.2 The Evolution of Space Concepts

In this topic, we limit our analysis to the presentation of the main conceptions of space directly related to the concept of work. They come from Euclidian geometry as well as the visions of the founders of mechanics concerning space.

2.2.1 Euclid (330–260 B.C.)

Euclid's *Elements* were published around 300 B.C. and undoubtedly had fundamental importance in numerous fields of knowledge, becoming a paradigm of knowledge in general. To emphasize its importance we can add that Newtonian mechanics and the special theory of relativity use Euclidian space as an essential part of their theories.

Before the appearance of *Elements*, geometry was not a completely systematized science. Geometrical knowledge of the ancient peoples were dispersed and disorganized. Egyptians knew several geometrical properties and how to apply them to many problems but they ignored logical relationships that linked and unified this knowledge. In other words, before Euclid the validation of geometrical knowledge occurred only empirically dictated by practical necessities. Egyptian knowledge was adopted by the Greek people, who developed it significantly. Thales, as an example, brought to Greece what he had learned from Egyptians in the seventh century B. C. This interchange of knowledge among several cultures with the development added by the Greeks permitted the establishment of logical connections within geometry. In addition, it became clear that geometrical knowledge is based on basic principles. Euclid realized this tendency and thus he collected and organized proofs, classifying the material and adding his contributions. Adopting this approach he concluded and demonstrated in his *Elements* that all geometrical knowledge is obtained through deductive method starting from five postulates and its consequent deductions. With this operation, the whole of geometry will be confined into the axioms from which the theorems are derived .[5]

These preliminary remarks lead us to say that the importance of Euclid is not only through the discovery of what postulates are true but even more so through the revelation of the five axioms that lead to geometry as a whole. Later on, David Hilbert, at the end of the nineteenth century, showed that Euclidian geometry can be derived through 20 axioms. He added one more, the completeness one. It is

[5] Leonard Mlodinov (Mlodinow 2004), p. 49, explains Euclid´s contribution: The most important Euclide´s contribution in "The Elements" was his logical and innovative method: first, by explicitating the terms, by formulating precise definitions and guaranteeing thus the understanding of all the words and symbols. In addition to become explicit the concepts presenting clearly the axioms or postulates (these terms are interchangeable) such that it cannot be used with understanding or suppositions not declared. Finally, to derive logical consequences from the system using only logical and accepted rules, applied to axioms and theorems previously proved.

Fig. 2.1 Latin translation of *the Elements* (twelveth century)

remarkable to note that in modern formulations the original five Euclidian postulates have accomplished a great number of derivations, and, because of their simplicity, they continue to be used nowadays .[6]

In terms of space theory, Euclid's *Elements* present the basic principle of his theory in the form of definitions and postulates, which determine an abstract world that, in the case of two dimensions, represents a plane. From this starting point, he derives the theorems in order to discover other evidence giving consistency to this geometric world. This means that deductions are logically valuables, and, if the axioms are true, the theorems are also true (Fig. 2.1).

It is not our objective to submit Euclidian geometry to epistemological analysis in order to study its consistency as scientific theory. However, it is important to discuss a fundamental concern of all theory that is its adequacy as a representation

[6] Concerning the logical consistency of Euclidian geometry or any axiomatic system, the history in general is as follows: In 1903, the philosopher and mathematician Bertrand Russell in his book, "Mathematical Principles", suggested that the whole of mathematics would be derived from logic. He tried with Alfred Whitehead to show how to do this in the book "Principia Mathematica", in three volumes, published between 1910 and 1913. In this book, the authors have affirmed the reduction of all mathematics to a unified system of basic axioms from which all theorems of mathematics could be demonstrated in a similar manner as Euclid tried to do with geometry. However, in 1931, Kurt Gödel demonstrated that statements that cannot be demonstrated must exist in an axiomatic system. As a corollary of this famous theorem, at least one true proposition that cannot be demonstrated must also exist in the axiomatic systems (El Nidditch 1995; Nagel et al. 1989).

of the real world. First of all, the axioms of Euclidian geometry being a set of propositions, this fact, in principle, would induce us to think that this theory could be false. It is not the case. A great number of mathematicians and philosophers have carefully analyzed this question and concluded that Euclidian geometry is a correct theory to describe physical space. This also implies another complementary question, also fundamental, that is, what experimental evidence should this theory present in addition to logical internal coherence? Thus, the next step will be to build experiments in order to test the predictions of the theory.

Obviously, if we should submit Euclidian theory to an experimental test, it would be by means of theorems. As an example, we examine the theorem of *internal angles* of a triangle. We can build a triangle in space, measure the internal angles and verify if its addition is equal to two straight angles according to the theorem.

At the beginning of the nineteenth century, the mathematician Karl Friedrich Gauss (1777–1855) accomplished a kind of experiment very similar to that which we are imagining. A question could be asked. Why was this type of test never done? Probably because, until that time, nobody had seriously considered the possibility of our physical space being non-Euclidian. In the experiment assembled by Gauss, the natural assumption that light beams travel in a straight line within the space was made. Thus, he has measured the internal angles of a spacial triangle the sides of which were light beams. This was done by assembling the equipment on the tops of three mountains, simulating a triangles' vertices. After measurements, Gauss confirmed the Euclidian assumption .[7]

2.2.2 Descartes (1596–1650)

The fundamental basis of Cartesian philosophy is the search for true knowledge, beginning with the decision *to be doubtful about all things found with minimum possibility of uncertainty.* This statement can be read in: *The Principle of Philosophy* (Descartes 1997) (Fig. 2.2).

From the historical point of view, Descartes is the father of modern philosophy and one of those responsible for the fatal blow against medieval philosophy, theology and dogmatism. His major accomplishment, as described by Roland Corbisier: "What did Descartes, his founder? (Of the modern philosophy) He does not start from the certainty, but on the contrary, from the doubt. He does not accept any dogma, any truth, unless it can be submitted to a critique, to a reason critique, becoming free from religious domination and theological alienation, rebuilding the autonomy and the right to be the last instance of truth. The rebirth of philosophy implied with the rupture of dogmatism, or, in other words, this rebirth was conditioned by the recuperation of freedom, by the reconquering of the right to think, to

[7] For a complete study of Euclid´s work, see (Heath 1956).

Fig. 2.2 **a** René Descartes (1596–1650), **b** First edition of Discours *de la Méthode*

criticize, to disagree. The first initiative, in Cartesian procedure, consists in eliminate of his belief all received opinion in order to replace that beliefs by others, betters, or the same opinions, since that be modified or "adjusted according to the reason".

The central thesis of Cartesian methodology is that knowledge is achieved through an act of the mind and not by experience: we can take into account many ideas and we can use our mental power to determine what is true. Such methodology, which is emphasized by Plato and Leibniz, is well known by rationalism. The opposite thesis, as we know, is empiricism, which is found in Aristotle and especially in Berkeley and Mach, where experience provides the basis for true knowledge.

Another important characteristic of Descartes' thought, for the study of the conception of space, is the distinction between mind and matter or material substance, that is, the difference between the thing that thinks and the thing that fulfills the space. To Descartes, all things except God are made by these two substances or understood by means of them. This concept of Descartes' was important at that time because things related to matter could be the object of scientific studies but only religion was permitted to be dedicated to matters of the mind, or the soul, without any interference in the progress of scientific development, and vice versa.

Descartes believed that the essential characteristic of matter is extension in three directions. He rejected such properties as hardness, weight, color and other properties that could define the characteristics of matter. This concept is fundamental to his understanding of space. To him, space is pure extension and, in addition, space and matter are the same thing. Obviously, to Descartes the idea of

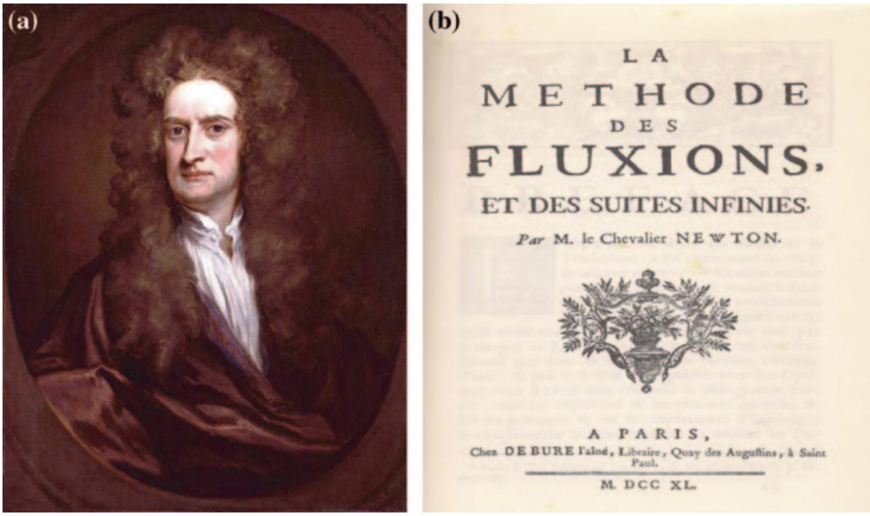

Fig. 2.3 **a** Isaac Newton (1642–1727), **b** French translation of *fluxions methods*

empty space is complete nonsense because empty space cannot exist. And yet, to him, Euclidian geometry correctly describes space if conceived according to his conception. However, the fundamental contribution of Descartes to scientific thought is obviously *Geometry*. This work, which is composed of other studies called Essays, appeared in 1737, when Descartes was 40 years old. Initially, this publication was known as *Discourse on Method*, with the sections on dioptrics, and the studies on meteors and geometry, added as appendices[8].

2.2.3 Newton (1642–1727)

It is worthwhile, in order to have a better understanding of Newton's work, to establish a comparison between both mathematicians, or, in other words, to compare Newton's *Principia* and Euclid's *Elements*. As we know, Newton's *Principia* is the fundamental reference of classical mechanics, and was published in 1687, while Euclid's book represents the original source of classical geometry, and was published around 300 B. C. (Fig. 2.3).

Euclid systematized geometrical knowledge, and Newton, in addition to this role with respect to mechanical knowledge, discovered the fundamental laws of

[8] Newton defines absolute space as follows: *The absolute space, in his nature, without relation with any external thing, stays always similar and stopped. Relative space is some dimension or moving measurement of absolute spaces to which our senses determine by his position with relation to bodies, and is usually considered not moving space…* (Newton 2002), p. 45

motion. However, there is a great similitude between Newton's *Principia* and Euclid's *Elements*. Their formats and presentation in the form of definitions and axioms, followed by proofs and propositions, are quite similar, as are their logical structures. In addition, both mathematicians were true investigators and followed the clues left by the thinking of their predecessors. Thus, the genius of both created geometry and classical mechanics.

From the point of view of our main concern, that is, the study of spacial conceptions in order to understand the development of this concept associated with the notion of mechanical work, Newton disagrees with Descartes' conception of space. To Newton, matter is not identified with space; his alternative vision is of absolute space and its independence of matter. Hence, Newton attributed a status of true knowledge to space as a kind of geometrical object, exactly as conceived by Euclid. To him, space is composed of points, a collection of points constructing lines, surfaces and solids having volume, and not properties of material bodies. In other words, all these notions are geometrical properties. These geometrical entities do exist in a form independent of material objects and their locations do exist before being occupied by material objects.

Space, to Newton, is also absolute in the sense that it exists even if there is no object inside of it. Its existence is independent of matter and it was in this sense that Newton thought of absolute space[9].

Unlike Descartes, Newton believed that space is quite different from matter in a similar way that objects are different among themselves. Thus, points, lines, surfaces and solids do exist and persist through time remaining the same size. On the other hand, absolute space is infinite, tridimensional, and rigid, as if a kind of Euclidian box that exists, immutable with time.

Newton also elaborated the concept of relative space which considers the position of an object in relation to another adopted as a reference. As an example, to fly a plane we need to know our relative position to a road. In other words, it is necessary to define a system of reference relative to a given object. In this reference system, Newton introduced the concept of relative motion[10].

[9] Newton distinguishes absolute and relative motions: *Absolute motion is the translation of a body from an absolute place to other; relative motion, the translation from one relative place to other. Thus, in a ship in motion, the relative place of a body… is that part of ship that is occupied by the body. But real not moving, absolute, is the permanence of body in the same part of that not moving space, in which the ship, its cavity and all that it contains, is moving… Because the parts of space cannot be seen or differentiated one with relation to others by our senses, we use realized measures by them. Although, from the positions and distances to things from any body considered not moving, we define all places, and then, with respect to such places, we estimate all motions, considering bodies as transferred from some places to others. Thus, instead of places and absolute motions, we use the relatives, without any practical inconvenience…* (Newton 2002), p. 45.

[10] This argument is emphasized by the publication of B. Russel´s book in 1900 about Leibniz philosophy. The author postulates that Leibniz philosophy was practically derived from his logics (Parkinson 1995).

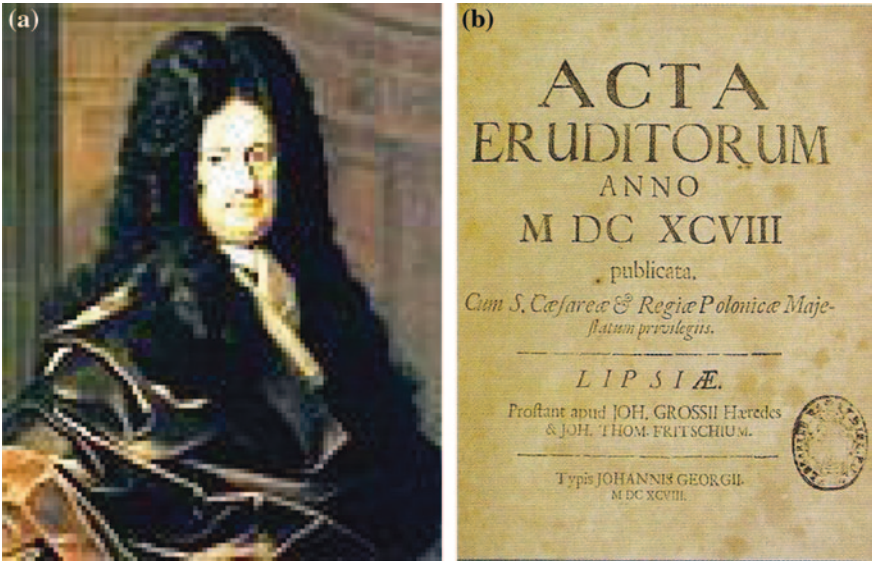

Fig. 2.4 **a** Leibniz (1646–1716), **b** Issue of Acta Eruditorum

2.2.4 Leibniz (1646–1716)

Like Descartes, Leibniz belongs to the rationalist school of philosophy. To him, geometry was a science related only to reason, and not dependent on any kind of experimentation for validation. Rationalists in general have applied this model to all knowledge and also defended their point of view based on basic axioms that permit the derivation of all facts in the real world.

Leibniz tried to accomplish an intellectual task of greater amplitude than Euclid. He postulated the idea that it may be possible to derive any knowledge (non-mathematical) from a general axiom, denominated in *Principle of sufficient reason* (Fig. 2.4)[11].[12]

If we look at Leibnizian conceptions of space, it is possible to characterize them as *relational*, Leibniz being the first thinker to present basic arguments and objections to the conceptions of absolute space and time proposed by Newton. According to Leibniz's vision, space is not an absolute substance but a *relational* category. This

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[11] According to Ross: *Leibniz´s approach tries to reconcile logical traditions, rhetoric and mathematics by putting together three distinct things (in formalism, in the linguistic property and in the mathematization) in a unique vision of a formal language of mathematical notation* (Ross 2001) .

[12] According to Daniel Garber, p. 302 of (Parkinson 1995), of the paper *Leibniz physics and philosophy, one reads: Leibniz was concerned with the notion of space in his early writings. Hence, there is a strong suggestion in some of these writings that he thought about space as something distinct from the body. In his writings from maturity he clearly denies the reality of space independent, particularly in opposition to the specific form in which it was presented by Newton´s writings.*

means that there is an *order* or a *situation* where bodies are related to themselves[13]. Looking at a relative reference system, we can determine relative positions of all bodies by taking one of them as reference, although any object can, in principle, be used as reference, such that it is possible to have a collection of objects with several relative distances to each other. As an example, Leibniz said that we can have the sun or the earth as systems of reference to the planets, being that there are different ways of describing relative distances among all of them.

And yet, Leibniz presents an opposite vision to that of Newton, according to which space is a substance separate from matter. His relational point of view affirms that without matter it is impossible for a *situation of objects* to exist, and consequently a relational space. There are essential differences between Leibniz and Descartes' thought. We shall discuss some of them in this chapter and later on.

It is important to note that some of Leibniz's ideas were adopted by Ernst Mach in his critiques of absolute motion, such that we can think about his work as the precursor to non-Newtonian mechanics. In addition, the dispute between Leibniz and Newton about the creation of infinitesimal calculus is well-known as one of the most famous of intellectual polemics. Finally, Leibniz made a fundamental contribution to the construction of the conceptual basis of classical mechanics; we will return to his thought on this in the discussion of the concept of force.

In order to finalize this section, it is important to emphasize the transformations of the conceptions of space that occurred in the fifteenth century, by means of the Renaissance artists. New forms of spacial representations changed the basis for new theorizations[14]. In different contexts, regarding the Scientific Revolution, Alexandre Koyré[15] and René

[13] Pierre Thuillier states: *It was in Florence, at the beginning of XV century (Quattrocento) that painters and architects have formulated the first theorization about perspective, theorization that would have later a profound repercussion on scientific thought. This fact will provide the projective geometry, as well as has stimulated the arising of space concept a fundamental concept to classical mechanics. The geometrization of space should be understood from a historical point of view, also related to a socio-cultural context very rich* (Thuiller 1994).

[14] Alexandre Koyré characterizes Scientific Revolution of the XVII century in the following form: *Although, I will characterize this revolution by two aspects closely related and still complementary: a) the cosmos destruction and, as consequence, the disappearing, in the science – at least in principle, however not always – of all considerations based on this concept; and b) the space geometrization, that is, the instauration of the dimensional space homogeneous and abstract – in spite of it nowadays could be considered real – of Euclidian geometry in replacing the positional and concrete continuum quite different from physics and astronomy pre-galilean* (Cohen and Westfall 2002).

[15] René Thom states: *I believe, that at the origin of Galilean Revolution there existed only the fact that scientific spirit has found itself in the situation to modelize, because precisely the notion of function, several phenomena, which were not previously modelized with good representation. In my opinion, two factors act combined: on one side, a series of practical needs, I think, mainly the artillery, which encouraged the study of the trajectories of cannon´s balls, of the projectiles, and, of the motion of heavy bodies; on the other hand, the notion of function, which is beginning to germinate in spirit of the investigators and then allowed them to describe, with precision and fidelity, the trajectory of a heavy body. I think, that the formation of this image of function – I say image, because function is here more one image than a concept – it was what originated the great galilaic Scientific Revolution* (Thom 1985).

Thom[16] also confirmed and emphasized the importance of these new forms of spacial representations in the development of Newtonian mechanics (Thom 1985).

2.3 The Development of Time Concept

Some historical and anthropological studies have shown that our conceptions of time have changed significantly throughout history. This fact has been reflected in language and has been demonstrated by the different notions that populations have had about the past, the present and the future. On the other hand, psychological studies focused in knowledge have indicated a strong interaction between the origins of the concept of numbers and the origin of language, as well as how our minds conceive the notion of time.

It seems clear that social forms of organization, the system of creeds and other cultural factors, affect our method of feeling and understanding time. Several authors have affirmed our linear conception of time as something associated with a straight line from the remote past to an infinite future was strongly influenced by Judeo-Christian heritage. In ancient Judaism, there were no cosmic cycles. God created the world starting from nothing, and after 6 days he rested. In addition, cyclic conceptions of time are probably directly influenced by the forms of economic production based in agriculture where products are subject to determined periods.

Independent of how these factors associated with social organization genuinely affect our notions of time in various societies, it is clearly possible to trace, in general, significant changes in our notions of history. And yet, in primitive societies, man had a transitional idea of time, as a flux with its inexorability, mainly associated with birth and death. Some rituals which arose in that time had the objective, in a magical way, of interrupting this continuous flux. Some clues to this type of ritual have appeared from the time of Neanderthal man around 60,000 years earlier.

During the Roman Empire, some interesting conceptions of time arose, and we should consider their contributions to more recent notions. One of them is expressed by Lucretius (94–55 B. C.) in his poem *De rerum natura:*

> *In similar way, the time itself does not exist; but from the existence of things a sense about what happened, what is happen and what will happen appear. We cannot say that some people would be possible to realize the time itself, independent of the motion of things or from it quiet immobility.*

Lucretius also remarked upon the relational aspect of time, which was a modern characteristic for that time, where a strong resistance to change beside veneration

[16] Marcel Conche describing the influence of Epicure on Lucretius affirms: He become concise, he develops, he enriches, he neglects and organizes in different manner Epicure´s thought, by giving a new life…(Conche 1981).

to authority was dominant. He was profoundly influenced by Epicurism and by pre-Socratic Greek philosophers, being too much difficult to identify in his thought the origins of these influences[17].

An important philosophical school with a vision contrary to linear time is Stoicism. In spite of the first Stoics having been Greeks, Stoicism became a very widespread doctrine among Romans. This philosophical school was founded by Xenon of Citrus around 300 B. C. He should not be confused with Xenon of Elea. A cyclic vision of time was a fundamental characteristic of Stoicism. As a consequence, all occurences are obliged to repeat themselves in unfinished cycles. And yet, according to the Stoics, at the end of each cycle, the entire cosmos would be destroyed in a huge conflagration before reappearing again. Inside this chain of fatalities, only human will was free.

As we know, there was no significant scientific progress during the Roman Empire. This situation began to change with the very important contributions to science by Arabic peoples. Around the nineth century, several scientific works and others of applied nature from the Hellenistic period were translated into the Arabic language. One such translation was of the famous book by Ptolemy, the *Almagest.*

At this time, Bagdad in certain ways replaced Alexandria in its role as the center of production and diffusion of knowledge. Greek heritage, along with Iranian and Indian traditions, were being assimilated and transformed by Arabians. This knowledge was transmitted to other Islamic countries, as well as to the south of Italy and to Arabian Spain where Cordoba and Toledo were the main knowledge centers of the twelfth century. During this period, devices for measuring time became necessary.

The Muslims needed people with mathematical knowledge to determine for them through astronomy the moments of the day mandated for prayer and the direction of Mecca. Thus, an appropriate device for measuring time was necessary for this purpose. At that time, the main instrument used was the astrolabe. It calculated fixed star positions with respect to the horizon, the sun and moon and the positions of planets related to stars. However, the more important use of the astrolabe was the determination of the hour of the day or the night through observation of the sun's height although these results are not sufficiently precise. Other instruments were also used to measure time. Water clocks have been in use since the time of Archimedes.

Lack of technical knowledge was the main difficulty in solving the problem of measuring time. This problem would be solved only with the development of the Scientific Revolution, which was just beginning at that time. Water clocks were scarce, expensive and only worked in some European cities.

[17] Viviani, Galileo´s disciple, wrote in 1659: *One day in 1641, during the period I lived with him in the village of Arcetri, I remember that Galileo´s idea that a pendulum could be adapted as watch with weights and springs, replacing the usual instrument…But because he had vision problems and couldn't draw and build models in order to determine what kind of device would better to obtain the desired effect, his son Vincenzo came one day from Florence to Arcetri and Galileo talk to him about the pendulum idea. The discussions were made during several days. Finally he decided to adopt the scheme showed in the drawings and to pass to practice by considering the fact that the difficulties that appear in machines usually are not predicted with simple theorization.* See Drake (1978), p. 153.

In spite of some doubts, the origin of the mechanical clock can be estimated around the end of the thirteenth century. One of the more important impetuses for development of the clock was the need to impose more discipline in monasteries. The religious ceremonies were believed to cultivate virtues and disobeying was punished with severity.

Besides these religious motivations, the increasing expansion of sea trade demanded new methods of navigation and the necessity of improving their precision. Latitude measurements could be done easily by traditional astronomical methods since the time of the Phoenician or even more ancient civilizations. Since the fifteenth century, ships were increasingly crossing the oceans and thus the determination of longitude became a real necessity. There were only two possibilities, the first by means of an astronomical prediction, which was impossible with the existing measurement instruments; the second was by means of a clock on the ship. Only around 1530 was a mechanical clock considered a feasible possibility. However, the clock models of this period based on a flywheel and circular escape motion did not provide accurate measurements.

The fundamental step towards obtaining an appropriate clock appeared with the idea of using a pendulum as the control mechanism. In 1591, Galileo realized the regularity of pendulum oscillations with small displacements. In 1641, he was concerned with the application of such a mechanism and designed a clock pendulum, which was built partially after his death[18].

At this time, Huygens (1629–1695), in the Netherlands, had made several modifications in the clock pendulum to achieve an improved version[19]. Despite this fact, the problem of building a clock pendulum that worked with regularity in ships was an unsolvable problem until 1726. An alternative method was found by Robert Hooke (1635–1703). This method was based on energy accumulated in springs, but further developments made by Huygens and Hooke did not solve completely the problem.

Only with the offering of prizes by governments was the solution of the problem of an embarked clock found. In 1714, the British government offered a prize of roughly 10–20 thousand pounds, depending upon the degree of precision obtained by the designed clock. The prize also required small variations of precision with large variations of temperature. A satisfactory solution was not obtained

[18] About Huygens ´contribution to building watches, mainly portable watches: *Before to present this communication, I should say, that there are in modern watches two springs in spiral form; one big drive spring, which move the whole machine and other so small, coupled to equalizer. This last one, also called regulate spiral, that we focus our attention now, because is that the object of Huygens' invention. Later on author affirms: The invention of the regulate spiral is dated of January 20th of 1675*. See Leopold (1982), p. 153.

[19] Michel Paty in (Paty 1988) remarks about the second principle of thermodynamics postulated by Sadi Carnot: *It is not the mathematical-physics, developed then about heat phenomena by Laplace, Poisson, Fourier, that the birth of a new science is determined, but Carnot´s observation according to which motion production in steam machines is due "not to a real caloric consumption, but to its transportation from one hot body to other cold body". The result was the second thermodynamics principle*.

until the middle of the eighteenth century by Harrison from England, Le Roy from France and Berthoud from Switzerland. The solution appeared independently with only a few years of difference. Harrison won the British government prize but further developments followed Le Roy's way in 1766. In the decades of the 1780s and the 1790s, a sufficiently precise model became dominant because of the great impulse towards maritime navigation.

Recently, with scientific developments, new problems have arisen with respect to the concept of time. First of all, the second principle of thermodynamics, established by Sadi Carnot in 1823, has given a sense to time, meaning that some natural processes are not reversible in associating the arrow of time with them. This kind of asymmetry is only theoretically validated by the second principle of thermodynamics because Newton's equations of motion are symmetric with respect to time. There is no difference in Newton's equations if time goes towards the future or towards the past.

Another remarkable fact in our conception of time was the arising of the special theory of relativity in 1905 (Stachel 2001). The experiences which prove the constancy of light velocity to any system of reference lead to the reformulation of classical mechanics laws and the substitution of the concept of absolute time by a time dependent on the system of reference.

In spite of this new perspective for the concept of time, both classical and quantum mechanics still use reversible time. Finally, it is important to emphasize that recent studies on dissipative system dynamics, the chaos theory where certain new concepts such as complexity and others appear, have created a new context with new questions related to time.[20]

2.4 The Concept of Force and Its Controversies

With the success of Newtonian mechanics for solving problems, mainly because of the application of differential and integral calculus using the second law of motion and by means of the Lagrange formalization one century later, the concept of force was established until the appearance of the general theory of relativity in 1916.

The opposition to Newton's concept of force came from the idea of universal attraction that he proposed in *Principia*. Thus, the concept of force was seriously

[20] Prigogine is much too clear to affirm: *We know that Newtonian conception about modern science was under the protection of almighty god, supreme guarantee of a rationality that appeared since the absolute monarchy. In this perspective, that attributes omniscience to a god that dictates the nature laws, the time couldn't be other thing but an illusion. In this sense we can say that our epoch is trying to rediscover the time. But initially it is worth to know, at the beginning of XX century, how we can conceive the relation between the historical time, irreversible, and physical time, reversible. It is interesting to see that there was a kind of consensus. Famous thinkers as Einstein, Bergson or Heidegger, in spite of their differences, they shared the idea that an irreversible time is not the objective of a true science*. See (Forti et al 1996).

contradicted by Cartesians, especially by d'Alembert. The Cartesians did not accept the propagation of forces at a distance, stating that this meant attributing to force a mysterious or metaphysical character to which Newton did not have a reasonable response. To Newton, the problem of completely understanding the concept of force was not solved because of the lack of a cause for producing a force at a distance.[21]

However, the critique of the concept of force had deeper roots than merely the heritage of old cultural elements since ancient times. Aristotle, as we know, did not accept the idea of a void. If the velocity impressed by force is proportional to it and inversely proportional to the resistance imposed by the medium, in a void the resistance would not exist, implying an infinite velocity. This impossibility justifies the impossibility of existence of a void. In addition to the force propagation, it is necessary for a medium to guide the force from the starting point to the point of arrival. Consequently, other conceptions appear to explain the motion of the planets around the sun, as well as several theories about media that fulfill the space. These theories and ideas encouraged studies that followed different directions. Ether's ideas influenced studies in fluid mechanics that also contributed to the building of electromagnetism and modern field theory.[22] The attempts to explain the action of gravity by mechanical processes is an alternative way to use any action at a distance. These theories were developed from the sixteenth to the nineteenth century ever related with the ether conception. René Descartes proposed in 1644 that no empty space can exist and, consequently the space must be filled with matter. According to him every motion is circular, so that the ether is filled with vortices. He also distinguishes different forms and sizes of matter in which heavier matter resists more strongly to circular motion.

Following similar Descartes's premises, Christian Huygens between 1669 and 1690 proposed a more exact vortex theory. His model was the first theory of gravitation which was represented mathematically. He assumed that the ether particles are moving in every direction but being thrown back to the outer borders of the vortex, thus causing a greater concentration of fine matter at the outer border.

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[22] According to Harman: *While Thomson has developed a theory of a continuum ether as a physical materialization of the full of Faraday´s force, Maxwell has explored the geometrical implications of the force lines, and also has developed a physical model to particles ether to represent a transmission of the field action through contiguous ether particles…Later the author states: The assumption about the elasticity of the magnetic-electric mean has permitted the generalization of the theory to electrostatics, with the elastic stress of the mechanical ether which corresponds to electrostatics field, and hence he has completed field mechanical theory of Maxwell. The theory had an unforeseen implication. Maxwell has calculated the speed of elastic transversal waves which corresponds to a propagation of an electric displacement in the magnetic-electric mean and has found that elastic transversal waves were transmitted with the same speed of the light waves*. He concluded: *light consists of transversal waves within the same mean which is the cause of electrical and magnetic phenomena.* See (Harman 1982), p. 84 and 93.

[21] About this problem Newton wrote as follows: *But, until now, I couldn´t discover the cause of these properties of gravity regarding the phenomena, and I do not invent hypothesis.* See (Cohen and Westfall 2002), p. 312.

In this model the fine matter presses the heavier matter toward the center of the vortex.

With these considerations Huygens also predicts that centrifugal force is equal to the gravitational force which acts in the direction of the center of the vortex. Newton developed at this time his theory of gravitation which is based on attraction. He also discovers that gravity follows the inverse square law and asserts that this is consistent with Kepler's law of motion. However, ether theory was overcome by Einstein's special theory of relativity in 1905, based on experiences that confirmed the constancy of light velocity.

Recent cosmological studies using the Hubble telescope have shown that there exists in the universe a dark matter and energy bringing back the notion of a subtle medium filling intergalactic space. Again, the theory of ether emerges in another scientific context.

The discussions about the concept of force are not restricted to a polemic against the Cartesians. Another important figure to criticize Newton's conceptual framework was Leibniz. (He criticized the Cartesians as well.) As was mentioned earlier, he did not agree with the concept of absolute motion and presented original ideas about the concept of force, as we will see. Leibniz's critique against the Cartesians, especially Descartes, is a very famous scientific dispute. The question refers to the quantity that is conserved during motion. To Descartes, that quantity is the *momentum*, while to Leibniz it is the vis viva, or kinetic energy.[23]

Because of its historical importance d'Alembert's disagreement with Newton's concept of force should be explained. D'Alembert not only criticized the Newtonian concept of force but proposed in his *Treatise of Dynamics*, published in 1743 (D'Alembert 1921), a new approach for solving the problem of a system of particles in motion. This proposal is known as the d'Alembert'principle. This principle has been transformed since its original formulation, starting from the dynamics of the problem of a shock of particles to a method for transforming a dynamic problem into a static representation. It appears in mechanics text-books without historical reference to those transformations (Oliveira 2001).

In his treatise, d'Alembert states: Hence, I have banned completely the forces inherent to bodies in motion, things obscures and metaphysical which are not capable to clarify but to bring darkness to a clear science by itself. He continues by discussing how to estimate forces which act on bodies, affirming: It is only by means of obstacles that are found by the body and by the resistance imposed… Mainly by the obstacles that a body can overcoming or by the resistance that it can opposes… more one can say if the force is big…Although is only in equilibrium or in retarded motion that one could search for measurements (of forces)…Then, in the equilibrium the product of the mass by the velocity, or, that is the same, the quantity of motion, can represents the force.

[23] In *Dynamics Writings*, (Leibniz 1991), p. 3, we find Leibniz´s vision with respect to the question of kinetic energy conservation (vis viva) about the famous debate with Descartes who postulated the constancy of the quantity of motion in the universe.

Obviously d'Alembert's concept of force is different from Newton's conception. The "controversy" is focused in this concept. In some aspects d'Alembert's approach for calculating forces coincides with the calculation of the variation of quantity of motion that is the effect caused by forces. In Newton's *Principia*, the second principle has established that if there are variations of motion, it is due to the presence of forces. Then, the two approaches are similar because Newton used the same model of impact that played a major role in Newton's dynamics, both in development and exposition of the concept of force, as well as providing insight into the third law. In fact, the differences appear because a mathematical representation in a differential form to unify both perspectives is missing. In 1752, Euler proposed that representation.

An important aspect of Newton's concept of force that is presented in *Principia* is the relation between the forces and motions produced by them. Starting from this point, he identifies absolute and relative motions. At the beginning of *Principia*, in *Definitions,* one reads: But we may distinguish rest and motion, absolute and relative, one from the other by their properties, causes, and effects. It is a property of rest that bodies really at rest do rest in respect to one another. And therefore as it is possible, that in the remote regions of the fixed stars, or perhaps far beyond them, there may be some body absolutely at rest; but impossible to know, from the position of bodies to one another in our regions, whether any of these do keep the same position to that remote body, it follows that absolute rest cannot be determined from the position of bodies in our regions. He continues: The causes by which true and relative motions are distinguished, one from the other, are the forces impressed upon bodies to generate motion. True motion is neither generated nor altered, but by some force impressed upon the body moved; but relative motion may be generated or altered without any force impressed upon the body. Newton then describes the famous experience of a rotating vessel to explain relative and absolute motion: If a vessel, hung by a long cord, is so often turned about that the cord is strongly twisted, then filled with water, and held at rest together with the water; thereupon, by the sudden action of another force, it is whirled about the contrary way, and while the cord is untwisting itself, the vessel continues for some time in this motion; the surface of the water will at first be plain, as before the vessel began to move; but after that, the vessel, by gradually communicating its motion to the water, will make it begin sensibly to revolve, and recede by little and little from the middle, and ascend to the sides of the vessel, forming itself into a concave figure (as I have experienced), and the swifter the motion becomes, the higher will the water rise, till at last, performing its revolutions in the same times with the vessel, it becomes relatively at rest in it. Because of the existence of forces acting on the vessel, exerted by the cord in the untwisted motion, there exists absolute motion of water, but the relative motion of it to the vessel could exist or not, as is pointed out by Newton. This experiment has two purposes. The first is to demonstrate the necessity of considering an absolute space as the better method for observing inertial forces acting on fluid mass. The second objective is to contradict the gravitational model proposed by Descartes, according to which the rotation of matter around the sun maintains the planets in their orbits.

Descartes made an analogy with the vortices generated by water flowing around some objects the velocities of which are greater close to them and smaller far away from them. That is what happens with the planets around the sun.

During the period 1680–1690, the same in which Newton worked on his masterpiece, Leibniz developed original ideas about the concept of force and motion. His considerations on force are quite different from Newton's and in some cases in opposition to them. To Newton, forces act on bodies as external attractions or repulsions. To Leibniz, force is a quality inherent to bodies, being an intrinsic property. Another difference between the two mathematicians is that Newton abandoned metaphysical consideration in spite of the fact that his concept of force at a distance does not provide a "scientific" explanation with respect to its propagation. In Leibniz, the explanatory framework of metaphysics comes back to help his construction.

Leibniz uses the concepts of primitive and derivative forces such that each one of these two types can be subdivided into active and passive.[24] Thus, it is possible to have primitive forces, active or passive, and derivative forces, also active or passive. According to Leibniz, primitive forces, active and passive, characterize the body constitution of a given substance. He states: *Primitive force distinguish itself from secondary force (i.e. derivative) which is called moving force is a limitation or an accidental variation of primitive force.* Derivative forces are the forces of more interest to physicists. Leibniz affirms: By derivative forces one denominates that which actually act one on the others or are actuated by others, I understand… only what is connected to motion (local motion) and, by the way, has the tendency to produce later the local motion.

He finalizes his comments as follows: Are these motions (i.e. derivative forces) to which the laws of action and reaction are applied, laws that are understood not only by the reason, but are also corroborated by common sense through the phenomena.[25]

Finally, primitive forces, active and passive, are the substantive parts of matter, while derivative forces, active and passive, are accidental forms or different ways for primitive forces to exist; likewise, the body form is an accident of one thing extended.

2.5 The Concept of Mass

If we analyze the concept of mass before Newton, we realize that it is confounded with the energy concept, obviously the form as to how this concept was understood before Faraday and other physicists of the nineteenth century. In the classical period, Empedocles' classification, according to which any substance is

[24] It is important to note that the concepts of primitive and derivative had been used by Leonardo da Vinci with respect to motion: Primitive motion is that which has the animated thing during the time that is linked to its cause. Derivative motion is that the animated thing has through the air after to be separated to its cause. Derivative motion has its origin in primitive motion and never has the speediness or power equals to speediness or power of this primitive motion. See (da Vinci 2004), p. 72.

[25] See (Leibniz 1991), p. 59.

constituted of some combination of earth, air, fire and water, was dominant for a long period of time.[26]

For the purpose of this book, the concept of mass comes from Newton and is one of the basic concepts of classical mechanics, this being the concept through which the principle of inertia (first law of motion) and the second law of motion are expressed. Obviously its invariability is assumed. Then, it is possible to distinguish mass and weight of a given body. Mass, using such a definition, also provides the definition of universal gravitational law because the force of gravitational attraction is related to the product of the masses involved and inversely to the distance of separation squared.[27]

After Newton, the concept of mass could be associated with chemical thought mainly through the works of Lavoisier as well as the energy concept. In a broad sense, the concept of mass is related to Einstein's equation $E = mc^2$, where mass and energy are interchangeable quantities. In his book *Out of My Later Years* (1950), Einstein presented the derivation of this equation in a concise way. It is important to note the simplicity of this derivation making use of only three previously known laws: (a) The law of the conservation of momentum; (b) The expression for the pressure of radiation, that is, the momentum of a complex of radiation moving in a fixed direction; (c) The expression for the aberration of light (influence of the motion of the earth on the apparent location of the fixed stars).

Lavoisier demonstrated, in the context of physics and chemical phenomena, the law of conservation of mass that one can enunciate as follows: *The total mass of a closed system stays constant for any physical–chemical transformation to which it can be submitted.*[28]

To achieve the above law, Lavoisier performed an experiment in 1768 which consisted of boiling water over a period of 101 days, measuring the weight of the whole system before and after this operation. This was done in a precision balance. It was observed that the whole weight remained constant.

This law permitted great advances in chemical transformation as the law of definite and multiple proportions, enunciated by Proust and Dalton. It expressed the relations among the elements of a chemical compound. And yet, of great importance for chemical purposes, was the periodic classification of elements, assembled by Mendeleyev in 1869. The criteria for classifying the elements is through the association of their properties with their atomic weights organized in a table of growing order. Another important experiment was performed by J. J. Thomson in 1897. He measured the ratio between mass and the charge of the electron in an

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[26] See *The Fragments of Empedocles*, 1973, pg. 35, translated by William E. Leonard, Open Court Publishing Company, Illinois, USA.

[27] The first quantity defined in Newton´s *Principia* is exactly the mass: The quantity of matter is the measurement of mass, obtained starting from his density and volume. See (Newton 2002), p. 39.

[28] Lavoisier wrote about this question: Indeed, I can consider the substances in presence one of the others and the obtained result, as an algebraic equation; and supposing successively each one of the elements of this unknown equation, one could find a value and to correct the experience by the calculation and the calculation by experience. See (Kahane 1974), p. 130.

experiment performed using discharges of cathode rays which were identified as electrons (Blondel 1994).

After some digression, we come back to the concept of mass as established by Newton. Then, we can also analyze the concept of inertia force as an inherent property of the body, meaning the resistance offered by the body to any change of its state of motionlessness or uniform motion in a straight line. It is worth emphasizing the difference between the inertia principle formulated by Newton and the alternative presented by Descartes based on motion conservation which was conceived in a geometrical perspective. Newton attributes a quantity to the concept of mass as the matter quantity of the body. In the context of Newton's second law, mass appears as a coefficient of proportionality between force and acceleration.

In recent times, starting from experiments performed with cathode rays (electrons), it was possible to detect a mass variation with velocity. The first idea was to associate this variation with a kind of electromagnetic mass in opposition to a mechanical mass without variation. What is observed is that electrons with very high velocities, near to light velocity as result of beta rays, have their total mass increased with this velocity without a constant residue which would be the mechanics mass. This fact provided some opposition to mechanics itself, as the fundamental theory of physics and some physicists tried to replace mechanics with electromagnetism. With the special theory of relativity, mechanics and electromagnetism had been put on a new basis.

With this new theory, mechanics was really refounded. It was also necessary to redefine the concepts of space and time according to the finite value of the velocity of light. The previous definition of mass had lost its meaning and its invariability, and was defined as $m = m_0/\sqrt{1-(v/c)^2}$ where m is the inertial relativistic mass, and varies with the ratio of the body velocity over light velocity. The value m_0 is known as the motionless mass that is Newtonian mass. According to the expression, to low velocities, both masses are equal. This variation of mass with velocity was demonstrated by Einstein in his third paper published in 1905, entitled: *On the Electrodynamics Bodies in Motion* (Stachel 2001).

As a consequence of this new theory, Einstein had established the equivalence between matter and energy by means of the equation $E = mc^2$, making possible the transformation of mass into energy as follows: $\Delta m = \Delta E/c^2$. This equation indicates that a mass variation is only viable for large amounts of energy. Hence, the possibilities of these transformations only occur in the field of high energies as radioactive transmutations with big liberations of nuclear energy.

Another problem related to mass in a Newtonian sense is the equivalence between gravitational and inertial mass. Using gravitational law $p = mg$ and $f = ma$, implying $f = p$ and $a = g$; then, gravitational mass is equal to inertial mass. This equality, used by classical mechanics, was not given a correct explanation for several years. Through a series of experiments performed by L. Eotvos, during the period 1890–1909, that equality was confirmed. Einstein, in 1907, thought the equivalence was between uniformly accelerated motion and a homogeneous gravitational field. These studies led him to the general theory of relativity, the *equivalence principle* becoming a fundamental principle of nature. As a consequence of Einstein's work between 1911 and 1915, this new theory showed a new structure of the physical world, the space–time determined only by the masses of physical bodies which contain and act as sources of field. Body motion obeys the equations of geometrical nature of the geodesic of space–time.

On 4 July 2012, the CMS (Compact Muon Solenoid) and the ATLAS (A Toroidal LHC Apparatus) experimental teams at LHC (Large Hadron Collider) in Geneva, Switzerland, independently communicated to the world that they each confirmed the discovery of an unknown boson. The experimental data indicates that the behavior of the new particle is consistent with a Higgs boson. This particle has been the subject of a 45 year hunt to explain how matter attains its mass. If finally confirmed, it will be the most important scientific discovery of the century (Fig. 2.5).

Fig. 2.5 **a** Components of LHC, **b** Traces of Higgs boson, **c** Table of quarks, leptons and bosons

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