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Part I

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Part I

Lectures

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On the Motion of Earth: the Dispute of the 17th Century and its followings until today

In ancient times[1], the Earth's rotation was considered responsible for the succession of nights and days. Later on, however, due to a literal interpretation of the Bible, the day-and-night alternation was chalked down to the Sun's rotation around the Earth. To make their case, fundamentalist Christian theologians were citing Joshua 10.12–13:

12 Then speake Josua to the Lord in the day when the Lord delivered up the Amorites before the children of Israel, and he said in the sight of Israel, Sun, stand you still upon Gibeon; and tou, Moon, in the valley of Ajalon.

13 And the sun stood still, and the moon stayed, until the people had avenged themselves upon their ennemies. Is not this written in the book of Jasher? So the sun stood still in the midst of heaven and hasted to not go down about a whole day.[2]

The battle over these Biblical verses was every bit as fierce as the one between Israel and the Amorites itself. Strictly interpreted, the passage was used against the concept of Earth motion: since it had been the Sun that stopped rather than the Earth, it meant the Sun was rotating around the Earth, which stood still.

As is well known, in Galileo's day, after a time of opening to the Copernican conception, the literal reading of the Bible was back in favor. There was also a somehow temporizing attitude among the Jesuit astronomers that would perhaps have put up with the idea of the Earth's motion provided they were offered some persuasive

[1] I. e. from the period of Pythagoreans. In the Plato and Aristotle's time, the Earth was considered still and the Sun, Moon, planets and stars moving around our planet. The Christians embraced the Aristotelian image of the Universe, as putting in the centre the man and his cradle.

[2] Authorized King James Version. In modern terms, these verses describe a genocide.

experimental proof which science was not yet ready to produce. The argument first took place on a philosophic ground and was considered close before astronomic observation had had a chance to come up with some evidence.

Galileo lambasted the fundamentalist reading of the Bible in his famous letter to Grand Duchess Christine (1613). Some illustrative excerpts of this letter, one of the most significant documents of the time, which would of course deserve to be cited in full, are given in loose translation below.

> "Now let us see the extent to which it is true that the famous passage in Joshua may be accepted without altering the literal meaning of its words, and under what conditions the day might be greatly lengthened by obedience of the Sun to Joshua's command that it stand still."
>
> "If the celestial motions are taken according to the Ptolemaic system, this could never happen at all. For the motion of the Sun through the ecliptic is from west to east, and hence it is opposite to the motion of the *primum mobile*, which in that system causes day and night. Therefore it is obvious that if the Sun should cease its own motion, the day would become shorter, and not longer. The way to lengthen the day would be to speed up the Sun's own motion; and to cause the Sun to remain above the horizon for some time in one place, it would be necessary to hasten this motion until it was equal to that of the *primum mobile*. This would amount to accelerating the customary speed of the Sun three hundred sixty times."
>
> "Therefore, if Joshua had intended his words to be taken in their proper sense, he would have ordered the Sun to accelerate its own motion in such a way that the impulse from the *primum mobile* would not carry it westward."
>
> "However, since his words were to be heard by people who were unlikely to know anything about the celestial sphere except that it moved from east to west, he stooped to their

capacity and spoke according to their understanding, as he had no intention of teaching them the position of the spheres, but merely of making them perceive the greatness of the miracle. It was perhaps this consideration that first prompted Dionysius the Areopagite to say that in this miracle it was the *primum mobile* that stood still, and that when this halted, all the celestial spheres stopped as a consequence—an opinion held by St. Augustine himself, and confirmed in detail by the Bishop of Avila. And indeed Joshua did intend the whole system of celestial spheres to stand still, as may be inferred from his simultaneous command to the moon, which had nothing to do with lengthening the day. And under his command to the moon we are to understand the other planets as well, though they are passed over in silence, as they always are in the Bible, which was not written to teach us astronomy."

"It therefore seems quite clear to me that, were we to accept the Ptolemaic system, it would be necessary to interpret the words in some sense different from their strict meaning. Guided by St Augustine's pithy precepts, I don't presume to say the above is necessarily the right meaning, as someone else may come up with a more appropriate, more harmonious one. But I wish to consider next whether this interpretation may not be more consistent with what we read in the *Book of Joshua* in terms of the Copernican system, adding some further observations on the body of the Sun. I do speak with caution and reserve, and not with such great affection for my own inventions as to put them above those of others, or in the belief that nothing can be brought forth that will be closer still more to the intention of the Bible."

"Suppose, then, that in the miracle of Joshua the whole system of celestial rotations stood still, in accordance with the opinion of the authors mentioned above. Now in order that all the positions should not be disturbed by stopping only a single celestial body, introducing great disorder throughout the whole of Nature, I will assume that the Sun, though fixed in one place, nevertheless revolves on its own axis, making a complete revolution in about a month, as I believe I conclusively proved in my *Letter on Sunspots*. With our own eyes we see this movement to be slanted toward the south in the more remote part of the Sun's globe, and in the nearer part to tilt toward the north, as all the revolutions of the planets occur. Third, if we consider the nobility of the Sun as the font of light which (as I will conclusively prove) illuminates not only the Moon and Earth but all the other planets, which are dark by nature, then I believe I will not seem to lack philosophical spirit by saying that the Sun, as the chief of Nature and in a certain sense the heart and soul of the universe, infuses by its own rotation not only light but also motion into the other bodies that surround it. And just as if the motion of the heart should cease in an animal, all other motions of its members would also cease, so if the rotation of the Sun were to stop, the rotations of all the planets would stop too. And though I could produce the testimonies of many distinguished authors to prove the admirable power and energy of the Sun, I will content myself with a single passage from the blessed Dionysius the Areopagite in his book *Of the Divine Name*, who writes thus of the Sun: *Its light gathers and converts to itself all things which are seen, moved, lighted, or heated; in a word all things are preserved by its splendor. For this reason the Sun is called HELIOS, because it collects and gathers all dispersed things.* And shortly thereafter he says: *This Sun that we see remains one despite the variety of essences and qualities of things that fall under our senses. It bestows its light equally on them and renews, nourishes, defends, perfects, divides and conjoins, nurtures, makes fruitful, increases, changes, fixes, produces, moves, and fashions all living creatures. Everything in this universe partakes of one and the same Sun by its will, and the causes of many things that are shared from him are equally anticipated in him.*"

"The Sun, then, being the font of light and the source of motion, when God willed that at Joshua's command the whole system of the world should stop and remain for many hours in the same state, it sufficed to make the Sun stand still. As it stopped, all the other motions ceased; the Earth, the Moon, and the Sun remained in the same position as before, as did all the planets; and in all that time, the day did not decline towards night, so that the day was miraculously prolonged. And in this manner, by the stopping of the Sun, without altering or disturbing any other aspects or the mutual positions of the stars, the day could be lengthened on Earth—which excellently agrees with the literal sense of the sacred text."

"But if I am not mistaken, there is something else that should not be neglected, namely that using the Copernican system we have the literal, clear, and easy explanation of another statement given in this same miracle, that the Sun stood still *in the midst of the heavens*. Serious theologians are in difficulty about this passage, for it seems reasonable to assume that when Joshua requested the lengthening of the day, the Sun was near setting and not at the meridian. If the Sun had been at the meridian, it seems unlikely that praying for a lengthened day would have been necessary in order to secure victory in battle. Since the miracle occurred around the summer solstice when the days are longest, the seven hours remaining before nightfall would have been sufficient. Serious theologians actually hold that the Sun was near setting, and indeed the words themselves seem to say so: *Sun, stand thou still.* For if it had been near the meridian, either it would have been needless to request a miracle, or it would have been sufficient merely to pray for some retardation. Cajetan is of this opinion, to which Magellan subscribes, sustaining it with the remark that Joshua had already done too many things that day before commanding the Sun to stand still for him to have done them in half a day. Hence the two theologians had to interpret the words *in the* *midst of the heavens* somewhat awkwardly, saying this means no more than that the Sun stood still while it was in our hemisphere, that is, above our horizon. But unless I am mistaken we may avoid this and all other difficulties if, in agreement with the Copernican system, we place the Sun in the *midst*—that is, in the center—of the celestial orbs and planetary rotations, as we indeed should do. Then take any hour of the day, either noon, or any hour as close to evening as you like, and the day would be lengthened and all the celestial revolutions stopped by the Sun's standing still *in the midst of the heavens*, that is, at the center, where it resides. This sense is much better suited to these particular words, as to everything else that has been said; for if the intended statement was that the Sun be stopped at midday, the proper expression would have been *stand still at noonday*, or *in the meridian circle*, and not *in the midst of the heavens*. For the true and only *midst* of a spherical body such as the sky is its center."

Galileo rebutted geocentrism in these fragments with other than scientific arguments, finding logical flaws in the interpretations of the Biblical passage, not in the Bible itself. It was therefore quite understandable that the dogmatic theologians should respond in ire.
We introduce here the readers to a fragment from the letter Bellarmine[3] wrote on April 12, 1615 to Foscarini[4] and implicitly to Galileo. The excerpt given below aims to illustrate the theologians' response—here, in a still contained but all the more threatening form. One will note how Bellarmine's reasoning diverged from Galileo's as

[3] Robert Bellarmine (1542-1621), a Jesuit theologian, elected cardinal in 1599, was a member of the Inquisition Court that condemned Giordano Bruno. For his fight with the Protestant theology, Bellarmine was sanctified in 1933.
[4] Foscarini was a Carmelite monk who wrote a letter to Bellarmine, in which he sustained Galileo's position that the Copernican theory is not in contradiction with the Bible.

well as the stern language of his letter. It was a collision of two great characters[5] and two different ages.

"First, it seems to me that Your Reverence and Signor Galileo act prudently when you content yourselves with speaking hypothetically and not absolutely, as I have always understood that Copernicus[6] spoke. For it is wise to speak of appearances and say that they are better saved by assuming that the Earth moves and the Sun stands still than by the use of eccentrics and epicycles. There is no danger in saying so and this is enough for the mathematician. But to affirm that in reality the Sun is at the center of the world and only turns on itself without going from east to west, and that the Earth is in the third heaven and revolves with great speed around the Sun, is a very dangerous thing, not only because it arouses all Scholastic philosophers and theologians, but also because it harms our holy faith by implying the Holy Scripture is false. Your Reverence has well shown many ways of interpreting the Bible, but has not applied them to particular cases; undoubtedly you would have encountered great difficulties if you had wanted to interpret all those passages you cited."
"Second, as you know, the Council prohibits interpreting Scripture against the common opinion of the Holy Fathers. Now your Reverence may have read not only their works, but even modern commentators on Genesis, the Psalms, Ecclesiastes, and Joshua, then you may have learned they all

[5] Both Galileo and Bellarmine were each in his own way very popular among their contemporaries. The frenzied throng of believers that turned out for Bellarmine's funeral tore off pieces of his clothes and devastated the mortuary to grab mementoes of the deceased whom they worshipped as a saint. Needless to say, the Protestant side of Europe reacted in a quite different way.
[6] Here and below, Bellarmine referred to two details concerning Copernicus' *Book of Revolutions*, namely the preface Andres Osiander had written probably without the author's knowledge, which cautioned the theory was merely hypothetical, and Copernicus' own dedication, which said it was only destined to mathematicians.

agree in the literal interpretation that the Sun is in heaven and turns around the Earth with great speed, and that the Earth is very far from heaven and sits motionless at the center of the world. Let us consider then in full prudence whether the Church can tolerate giving Scripture a sense contrary to that of the Holy Fathers and of all Greek and Latin commentators. Nor can one claim that this is not a matter of faith, since if it is not a matter of faith in terms of the topic, it is so in terms of those that talked about it. Thus he who would make such assertions would be just as much a heretic as he who would deny that Abraham had two sons or that Jacob had twelve or that Christ was born of a virgin, because all this is said by the Holy Spirit through the mouth of the prophets and the apostles."

"Third, I say that if there were a true demonstration that the Sun is at the center of the world and the Earth in the third heaven, and that the Sun does not circle the Earth but the Earth circles the Sun, then one would have to proceed with great care in explaining the passages of the Scripture that appear contrary, and rather say we do not understand them than say that what is demonstrated is false. But I will not believe that there is such a demonstration, until it is shown me. Demonstrating that the appearances are saved by supposing the Sun to be at the center and the Earth in heaven is not the same as demonstrating that in truth the Sun is at the center and the Earth in heaven. I believe the first demonstration may be available, but I have very serious doubts about the second, and in case of doubt one must not abandon the Holy Scripture as expounded by the Holy Fathers. I add that the one who wrote, *The sun also ariseth, and the sun goeth down, and hasteth to his place where he arose*, was Solomon, who not only spoke by divine inspiration, but was a man above all others wise and learned in the human sciences and in the knowledge of all created things, a man whose wisdom came from God. It is therefore unlikely that he would have asserted anything contrary to truth already demonstrated or capable of being demonstrated. Now, if you tell me that Solomon speaks according to appearances and that it seems to us the Sun turns while the Earth does so, just as it seems the shore is moving to someone who moves away from it on a ship, I shall answer as follows: Whoever moves away from the shore, although it appears to him the shore is moving away from him, nevertheless he knows this is an error and corrects it, seeing clearly it is the ship that moves and not the shore; but in regard to the Sun and the Earth, no scholar has ever thought there was any error to correct, since anyone clearly senses that the Earth stands still and that the eye does not mislead him when he considers that the Sun moves, as it does not mislead him when he considers that the Moon and the stars move. And this should be enough for now."

The birth of the Newtonian theory in the frame of theoretical astronomy and the development of philosophical reflection rejecting anthropocentrism[7] led to the victory of heliocentrism.

The Earth's motion is a rather complicated one. It consists of several components, two of which are more easily perceived owing to their short-term consequences; they are the daily spin on its own axis

[7] Reconsidered and revaluated from a different perspective, anthropocentrism is back, as science tries to establish the way in which the mere existence of human life in the Universe affects natural laws. A step-by-step reconstruction leads us to believe that it took a very close fine-tuning of the various basic physical quantities to ensure an evolution such as the one that led to man's appearance. The slightest alterations of these values would have driven the evolution of the Universe into a dead-end in which life, as we know it, would have been impossible. The results arising from the use of the so-called "anthropic principle," which takes into consideration human existence and projects it on the history of the Universe, have sparked a number of debates, including some with a teleological and metaphysic touch. The anthropic principle stops short of putting man at the center of the universe, but it does put him in a quite favorable position and in a less troubled period of matter evolution. By focusing scientific attention on man, the principle leads to a series of conclusions that are extremely valuable to various areas of knowledge.

resulting in the succession of day and night and the annual motion around the Sun, which leads to the succession of the seasons due to the tilt of the Earth's axis with respect to the plane of its orbit.

Precession and nutation are the two other major motions of the Earth. To better understand them, we may compare the Earth to a top. Precession is a motion by which the top's axis defines a cone while remaining inclined at the same angle with respect to the plane on which it rests. Nutation is a slight wobble of the axis off its median position represented by the side area of the precession cone. The Earth's precession results in a shift of the North Pole, which completes a circle every 26,000 years; as a result our North Star is not always the same star but rather the closest one to the place where the Earth's axis "thrusts" into the sky. The Earth's nutation leads to a shift of the Moon's nodes with an 18.6 years period.

As seen from Kepler's letter to Galileo earlier quoted in this volume, contemporary astronomers were trying to use telescopes in order to reveal the Earth's revolution around the Sun. The idea of such observation dwelled on the effect known as parallax, which consists in the changed perspective of a star when it is looked at from different locations on the terrestrial orbit. As a result of a complete revolution of the Earth, a star closer to us describes a small ellipse, known as parallax ellipse (Fig. 1), against the backdrop of the farther stars. The visual rays from two diametrically opposed locations on the terrestrial orbit make up an angle known as the annual parallax of a star. By determining the angle one can calculate the distance to that particular star. This angle, however, decreases with distance, therefore the closer a star is to the Earth, the smaller the angle, which accounts for the fact that the parallax could not be measured in the early 17^{th} century.

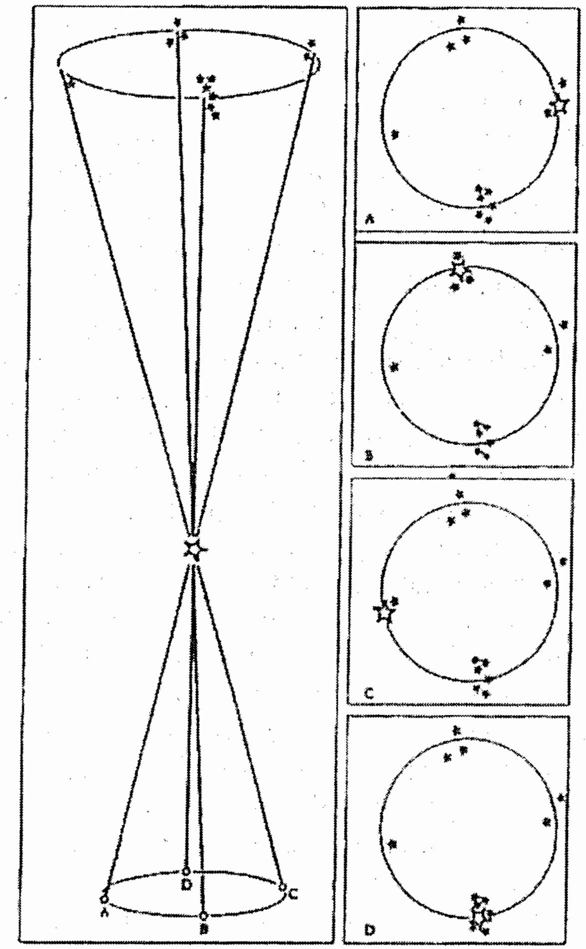

Fig. 1. Parallax of a star. The annual motion of the Earth generates an apparent motion of the closer stars against the background of the farther ones. Four Earth positions, two of which are diametrically opposed to the other two, are represented on the left. The different positions of the same star, as seen from these four points, are given on the right.

Until astronomical instruments with lenses and mirrors were developed, the most accurate measurements had been the work of Tycho Brahe (1546–1601) who successfully measured angles to an accuracy of 1–2 arc minutes.[8] Galileo's telescope was able to enlarge images up to 30 times, but its accuracy was hampered by distortions.

In the third decade of the 18th century the English Astronomer Royal James Bradley (1692–1762) produced the first astronomical proof of the Earth's motion. It came from an unexpected direction since the physical phenomenon that helped provide this proof was the aberration of light. The speed of light[9], though very high, is finite, hence consistent with the Earth's speed of 30 km/s. As a result, the direction of a star ray is shifted by an angle, which though being quite small can still be measured. This angle depends on the relative direction between the ray of light and the Earth's speed at that moment. Since the Earth's speed modulus is nearly constant, the maximum aberration has the same value for all stars, namely 20 arc seconds from the median value. This is precisely what Bradley found for the star Γ Draconis.

Another century had to slip by until the first annual parallax of a star could be determined. It was F. W. Bessel (1784–1846), the great German astronomer and mathematician, that discovered it. In 1838, pointing the telescope he had made himself at the star 61 Cygni, he measured a parallax of 0.31''[10] and deduced the distance to be 11 light-years. It was the first time that the distance to a star had ever been measured. Bessel's measurement was 6,000 times more accurate than Tycho Brahe's ones had ever been.

The Earth's diurnal rotation was proved by the French physicist J. B. L. Foucault (1819–1868) in a famous experiment he presented at the Paris Exhibition in 1851. Foucault used a pendulum consisting of a

[8] 1' = 1/60 of a degree.

[9] Several years earlier, the Danish astronomer O. Römer had determined its value to be quite close to 300,000 km/s, as very accurate terrestrial measurements later on revealed. To determine the speed of light, Römer had used Jupiter's moons discovered by Galileo.

[10] 1'' = 1/60 of a minute of an arc.

very long wire with a canon ball at its end, and placed a stylus under the ball. Once the pendulum was set into motion, it tended to go on oscillating in the same plane while the Earth rotated. As a result the stylus cut traces forming a rosette on the graduated round dial underneath (Fig. 2).

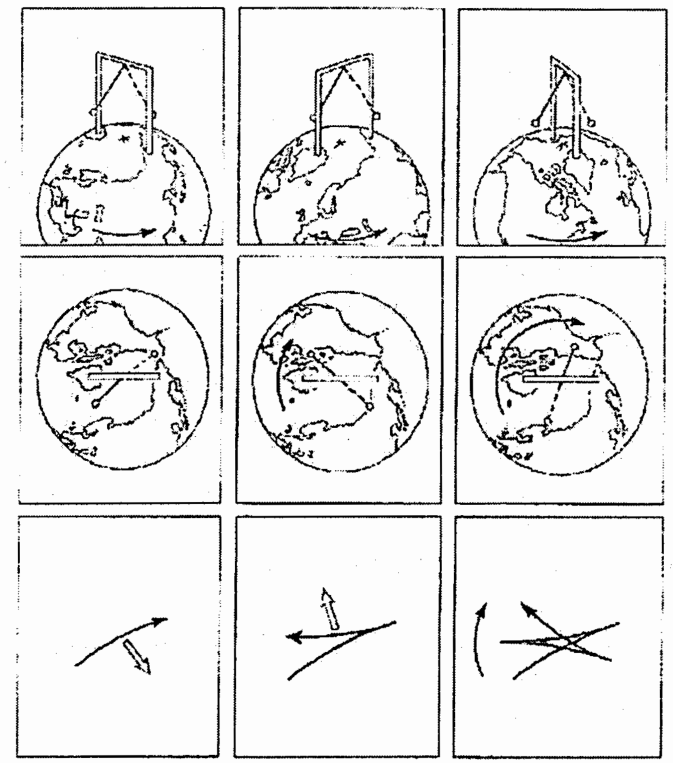

Fig. 2. The Foucault pendulum set up at the North Pole. a) The rotation plane stays unchanged while the Earth turns under it. b) To an observer on the Earth the oscillating plane looks as if it were rotating, as indicated by the arrow. c) The apparent motion of the oscillating plane is caused by the Coriolis force, which acts as the arrow shows.

In principle, Galileo himself could have done this experiment with no more equipment than a chandelier and would thus have produced the proof of the Earth's rotation he so much needed at the time. Interpretation is no problem given the intuitive nature of the experiment, and sitting by the pendulum, Galileo would not have had to wait too long to notice the effect.

Two decades before Foucault's experiment, the French mechanician G. C. Coriolis (1792–1843) had succeeded in proving that a force, now known as the Coriolis force, is exerted on a body that moves in a rotating system. An observer standing inside the system can easily perceive the effect of this force on the pendulum, which materializes in the earlier mentioned rosette. By contrast, an outside observer cannot notice the action of the Coriolis force; he only sees the system rotating while the pendulum keeps oscillating in the same plane. In other words, the Coriolis force is the "absolute" proof of the rotation of a system that one can establish from within the system. In the northern hemisphere as a consequence of this force, rivers wear away their right banks more than they do their left ones, and water currents and cyclones turn clockwise. In short, proofs of the diurnal rotation were at hand even in Galileo's time, but people lacked the theoretical background to notice them. Besides, a view of the Earth as a whole had not yet developed.

Aside from the above four motions, which are "individual," the Earth along with the entire solar system takes part in the rotation of the galaxy, the expansion of the Universe, and the rotation of the local group of galaxies. The first motion having a period of about one hundred million years is relatively slow. The expansion of the Universe was discovered in 1929 by the American astronomer E. P. Hubble who found that the spectral lines from faraway galaxies shift to the red side of the specter. Knowing that the frequency of light from a source increases as the source draws nearer to the observer and drops as the source recedes (Doppler effect), it was established that the galaxy clusters move apart from one another at a speed proportional to the distance between them.

According to current cosmological theory, this expansion is the result of an explosion of very hot, very dense primary matter—the big bang—that occurred some 15 billion years ago (see Steven Weinberg, *The First Three Minutes*, Chapter 2). Up to a point radiation and the created matter (in particle–anti-particle pairs) were at equilibrium. Then, as density decreased through dilatation, radiation no longer interacted with matter except sporadically; eventually, radiation and matter broke apart and every one of them continued on its own. As the Universe went on expanding, radiation gradually cooled down to its current temperature of 2.7 K (about –270 degrees Celsius). Discovered in 1965, this radiation—a leftover from the time photons separated from matter—appears in the form of microwaves and is scattered all across the Universe. Matter also cooled down, generally speaking, but its evolution was far more complicated. Matter has always been under the influence of gravitation, so that starting from little, local density fluctuations, it began to agglomerate resulting in the structural forms—stars, planetary systems, galaxies, clusters of galaxies, etc.—currently known to us.

This accounts for the fact that the 2.7 K radiation has kept the ideal characteristics of Universe expansion to this day, while matter no longer had any influence on it from some moment on. The distribution of radiation across the Universe is remarkably even compared to that of mass. It provides a reference point in an ideal, even motion of expansion.

The microwave radiation does have some inhomogeneities, the most relevant of which for our topic lies between plus and minus 0.26 percent. The temperature of the microwave radiation is by 0.004 K higher than average when the directional antenna points at the constellation of Leo and lower by 0.004 K for the diametrically opposed area of the celestial sphere. This temperature variation is at the same time a frequency variation of the microwave radiation. Based on the same Doppler effect, one concludes that the observer is moving toward Leo at about 390 km/s. Since our solar system takes part in the rotation of the galaxy, it means that with respect to background

radiation, our absolute reference point, our galaxy is moving at about 600 km/s. This deviation from the even expansion of the Universe is due to, so to speak, 'local' inhomogeneities in the distribution of matter. Some place far away in the current direction of the constellation of Leo there is a huge agglomeration of matter that attracts our galaxy and makes it drift.
For now at least this puts an end to the controversy over absolute motion that aroused such passions and claimed so many efforts for nearly four centuries. The absolute motion of the Earth, which Kepler and Galileo and other contemporary astronomers sought to determine with respect to what they thought were 'fixed' stars, is now linked to a moving, 'immaterial' reference point, the existence of which no one even suspected a few decades ago.

Max Planck (1858-1947) on the relations between Science and Religion

Abstract

After a brief biographical presentation of Max Planck, the father founder of Quantum Theory, the problem of the relations between Science and Religion is discussed. Planck's contribution in this field reveals itself as important not only from the historical point of view, but also for the originality and force of argumentation. His definitions of Science and Religion are analysed. Max Planck has a lot of ideas in common with critical realism, both in Science and Religion. Planck considers Science and Religion different in their approaches, non-contradictory, and reciprocally completing each other. The peace of mind remains the main goal of Religion and Science, and that can be obtained searching the Truth in both fields.

Very seldom so many qualities were cumulated in a same person as it happened to be the case of Max Planck, who founded a hundred years ago the Quantum Theory.
The centennial anniversary of Quantum Mechanics on December 14, 2000, was an occasion to remember not only the great German scientist, but also the profound and original thinker who he was. Indeed, Planck meditated deeply at the destiny of his profession, at the philosophical signification of the new Physics and its relations with Religion along a period of many changes in Science, Philosophy and Theology, which took place on the ever changing social and political background, and drastically transformed our world.

Max Planck's texts are not only simple remarks which accompany usually the most important scientific papers of many authors, but complete articles and communications entirely consecrated to subjects involving this domains, approached by their author with the same profundity as his scientific works. In other words, Max Planck was not an occasional philosopher or theologian, but a scientist with a real vocation of universality. This category of papers, namely *Scientific Autobiography, The Meaning and Limits of Exact Science, The Concept of Causality in Physics* and *Religion and Natural Science* were edited together with the *Memorial Address* delivered by Max von Laue at the funeral of his teacher on October 7, 1947, in a volume entitled *Scientific Autobiography and Other Papers*, ref. [1]. In spite of being partially known to German scientists from author's communications, these essays became accessible to the large public only due to their publication in volume after the death of Max Planck.

In the words of Max von Laue, (ref. [1], *Introduction*), Max Planck, his teacher and elder friend[1], lived "almost four-score-and-ten ... a long life, and these particular ninety years were extraordinarily rich in experiences", from the times of "Prussian and Austrian troops marching in his native town of Kiel" to "the destruction of Kassel, where he was buried in an air raid shelter for several hours" during the WW2. Max Planck's life was also marked by personal tragedies: he lost his eldest son, Karl, who died in action at Verdun in 1916, and his second son, Erwin, in January 1945, during Hitler's terror.

In his professional life, Planck had also considerable obstacles to overcome: in his *Scientific Autobiography*, he repeatedly complained (ref. [1], pp. 18, 22, 23, 30, etc.) about the long period in which "literally nobody at all had any interest whatever" for his papers and

[1] Max von Laue had a great esteem for Planck (see ref. [2]). The feelings of both were reciprocal; in his *Scientific Autobiography*, (ref. [1], p. 42), Planck wrote with consideration about his "closest pupil, Max von Laue".

his field of research, which opened nevertheless a new era in the contemporary scientific thinking and in our very image about Nature.
Another important fact completes the intellectual portrait of the founder of Quantum Mechanics, showing a tragic feature. In spite of his giant theoretical opening towards the new branch of science, Planck remained in a sense an adept of Classical (i. e. non-quantum) Physics. Together with his protégé[2], Albert Einstein, Planck was reticent to the subsequent development of Quantum Mechanics.

Max Planck graduated from the Maximilian Gymnasium in Munich and studied Experimental Physics and Mathematics first in Munich, and then in Berlin, where he had as professors famous German physicists Hermann von Helmholtz (1821-1894) and Gustav Kirchhoff (1824-1887), who will influence him not only as a first class professionals, but also in the broader sense of intellectual horizon and human relationship. The respect paid by the young student and then, PhD student, to his scientific masters didn't prevent Max Planck to judge quite severely their shortcomings and, in some sense, their shortsightedness, especially in connection with his PhD Thesis (1879), consecrated to the key problem of entropy.

From the very beginning of Planck's scientific career[3], a special characteristic must be stressed: the young man approaches originally the classical subjects, like the principles of Thermodynamics, with the declared aim to improve their formulation. He attaches a special attention to the main concepts of Physics, which, by their special position, play a determinant role in the perception of the world. He

[2] Max Planck played the main role in the nomination of Einstein at the Berlin University in 1914.

[3] It is interesting to mention a fact that completes the intellectual portrait and characterizes his open mindedness. During his early period at the Institute of Theoretical Physics in Berlin, Planck received a task in a field far from his own one, namely to study the untempered "natural" scale of a large harmonium then at his institute. Planck brilliantly accomplished this mission.

regarded the entropy (his beloved subject) as "next to the energy, the most important property of physical systems" (ref. [1], p. 20).
Soon after completing his paper dedicated to *The Nature of Energy*, which will receive a prize from the Philosophical Faculty of Göttingen, Planck was nominated assistant professor at the University of Kiel (1885) and then, in Berlin (1889). In 1892, Max Planck obtained the title of full professor of Theoretical Physics, as a successor of Helmholtz.

Step by step, his career enters a more quiet, 'normal' flow, not without fighting again the established authorities, like the well-known scientists Wilhelm Ostwald and Ernst Mach, the promoters of the so-called 'energetism', who disputed *inter allia* the existence of the absolute scale of temperatures. Planck's eventual victory against the adepts of energetism was divided with Ludwig Bolzmann (1844-1906) and facilitated by a series of circumstances external to the pure scientific arguments. In his *Autobiography*, Max Planck recognises openly the leading role played by Boltzmann in the dispute and the fact that, in spite of his own decisive theoretical contribution, Boltzmann alone could have obtained this victory without him. Planck's arguments were acknowledged by Boltzmann only in the last years of his life, after realising that they have in common the atomistic foundation of theories of which Boltzmann was an early advocate.

The retard of community of scientists in recognising the value of new scientific contributions (not necessarily only his own ones) makes Planck to write bitterly: "This experience gave me the opportunity to learn a fact – a remarkable one, in my opinion: A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it." This idea influenced Thomas S. Kuhn's in the elaboration of his theory about the scientific

revolutions and the advancing of scientific knowledge, (ref. [3]), published in the early-sixties[4].

The most important moment in Planck's scientific life was the communication delivered in December 14, 1900 before the German Physical Society, having the title *On the theory of energy distribution of a normal spectrum*, ref. [4]. In this work, Planck offers a new formula for the energy distribution of a normal spectrum, which fits the experimental values both for the ultraviolet and infrared limits of emission spectrum. The existing classical theories could explain only one part or another of the energy distribution, but never the entire spectrum.

The completely new approach made by Planck was to regard the bodies emitting electromagnetic radiation as consisting from a large number of independent oscillators of different frequencies. The energy of radiation was considered as a sum of elementary portions not divisible *ad infinitum*; each portion being a multiple of a fundamental constant, *h*, multiplied by the frequency of the oscillator, which emitted it. This picture explained the entire normal spectrum of electromagnetic radiation. Later, through the explanation of photoelectric effect, Albert Einstein will extend the discontinuity from the act of the emission to the absorption of electromagnetic radiation, making the connection with the discreet structure of energy in atoms. This new conception was a revolution, which changed fundamentally our conception about the processes at the microscopic level in Nature.

Not without reluctance, the Planck's theory was accepted step by step and, in 1918, he received the Nobel Prize for his works about the energy distribution of the electromagnetic radiation spectra. Universally recognised as the father of Quantum Mechanics, Planck

[4] Thomas S. Kuhn quotes this fragment from Planck's *Autobiography* in [3], p. 151, together with a similar statement of Charles Darwin. We can find it also at Max von Laue, ref. [2], chap. 8, in a similar context.

was also a giant of Classical Thermodynamics, and the main promoter of the concept of Entropy, which is so tightly connected with the evolution of the physical systems and of the Universe as a whole. He wrote also fundamental handbooks and treatises, which remained as standards for many generations of students.
A reputed professor, Planck attracted the students and helped in their professional career brilliant young scientists. Two examples, Albert Einstein and Max von Laue, are conclusive in this respect.
Planck's lifetime covered also very troubled political periods during which, in spite of the inherent difficulties, the German scientist kept a dignified attitude without compromises. We shall see that between his life and his work, including the essays considered here, there is a complete harmony.

In this lecture, we will examine mainly two papers, namely *The Meaning and Limits of Exact Science* and *Religion and Natural Science*, which are, as it can easily inferred from the very title, in a tight connection. Before starting, we must define some terms used by Max Planck, which can differ from those used generally in the literature, as being important for understanding correctly the author. Generally speaking, founding comprehensive definitions for Science and Religion is by itself a very difficult mission, due to the complexity of phenomena and notions implied by the two domains. What is the exact science in Planck's vision and what is its role in the human knowledge? At the first glance, Planck's image of Science is a romantic one, inspiring in the author's words "a vision of a lofty structure, of imperishable slobs of stone firmly joined together, treasure house of all wisdom, symbol and promise of the coveted goal for a human race thirsting for knowledge, longing for the final revelation of truth. And since knowledge always means power, too, with every new insight that Man gains into the forces at work in Nature, he always opens also a new gateway to an ultimate mastery over them, to the possibility of harnessing these natural forces and making them obey his every command." (ref. [1], p. 80).

But, stresses Planck, knowledge and power represent only a part of the outcome of Science, and not the most important one. More important are the ideology and philosophy of life, which follow from the knowledge of Nature, as they can bring us the most precious thing on the world, the peace of mind. If the Religion cannot offer us this state of spirit, the Man turns his face to Science.

In the following, Planck modifies this ideal representation of the edifice of Science, sustaining that it is build on a moving ground. To support this change of the model in the framework of which Science is seen like an inexpugnable fortress, Planck invokes the failures to establish an exhaustive, unchangeable, universal and aprioristic fundament for Science, in spite of the efforts of great philosophers "from Thales to Hegel". Planck's declared aim is to fight with the disappointment, which follows from this difficulty.

For the beginning, the German physicist assumes a more modest goal: "to cast a light both on the meaning and limits of exact Science. So, we must be satisfied initially to discover some form of truth, which no scepticism could attack. In other words, we must set our sights not on what we would like to know, but first on what we know with certainty." (ibid., p. 84). This certainty is offered by the sensory impression which is always a given fact, and therefore incontestable. Nevertheless, between the subjectivity of individual sensations and the necessity of earning an objective and universally valid knowledge seems to be a contradiction. Can the sensations be a starting point for Science? Planck's answer is affirmative. Through measurement, the sensations can be translated in numbers, which are the main input for the subsequent logical, mathematical and philosophical analysis. Science introduces order and discovers the regularities in the heterogeneous richness of the sensorial world. From this point of view, in its development, science doesn't proceed in a very different mode than a child who, while growing, starts step by step to know the surrounding world, using first his own sensations, which he processes using his own mind. The difference comes from the systematic, organised mode of scientific activity, and from the fact that science represents a collective and historically cumulated effort.

Max Planck's analogy between the individual human development and the process of scientific knowledge goes further like the parallel between ontogeny and phylogeny. The external reality of Man is not a given one; it is not a notion directly inculcated **ab initio**, but the result of evolution, of the gradual and repeated experience, of the practice. It is a changing reality, based on the process of learning, more rapid in the childhood, more slow in the adult years. A similar image can be conceived about Science. Nor Science has a unique, direct and final picture of the object of its study. As the new knowledge accumulates, an internal image forms, which is permanently confronted with each new experiment. Every mismatch that appears is, in the individual scientist case, as well as in the case of Science as a hole, an object of wander and a reason of concern. The feeling of wander, the experience of unusual lay at the fundament of discovery and many scientists wrote about these moments of their life, from Galileo (about miracles), to Einstein (about mysteries), considering them essential for their creativity. Both miracles and mysteries are gradually included in the corpus of science, loosing their paradoxical character.

The result of this continuous process is the real world of science, which is a derivative of the real world of human experience, without being identical with it. The real world of science is not reducible to the sensations, which originate from the world of human experience, nor to the momentary picture inspired from it. If in the "classical" world the elements of the "real" were the "atoms" which explained the Chemistry by (then) circa 90 varieties from the periodical table, in the post-classical Physics, the elements of the "real" are the electron and the proton. Of course, meanwhile, the elements changed again and it is expected that they will change again in the future. Does this evolution

of scientific images of the "reality" zigzag, or approach asymptotically towards a better description? Planck's choice is the second variant, that of the progress and improvement. (ref. [1], p. 100). What kind of progress? What is the final goal of science? Does the final reality exist? In Planck's conception the ultimate reality will never be reached and cannot be reached in principle. It is not "behind" the reality, nor above it, but "within the reality itself". Nature doesn't possess a "kernel" or a "core", Nature is a whole (ibid., p.102).

The essence of the ultimate reality pertains to Metaphysics. If Science doesn't have an access to the ultimate reality, what is its purpose? Max Planck defines it as the discovery of laws of Nature, which have an approximate character. The result of scientific activity is, therefore, a moving picture, which undergoes a remake with every new discovery. So, at the end, Max Planck arrives at a different model of Science and, instead of an unmoved citadel, we have now a dynamic, unfinished and perfectible structure.

It is a realist scientific point of view, which rejects the positivism or instrumentalism, presented by Planck under the generic label of scepticism. Planck's opposition to sceptics is based on the general arguments of scientists, namely the possibility offered by the sciences to know progressively the material world, to describe the reality. In fact, Planck's conception about Science represents the position of critical realism, a current of thinking that was characterised by Arthur Peacocke as recognising "that it is still only the aim of science to depict reality and that this allows gradations in acceptance of the 'truth' of scientific theories. It is a 'critical' realism about the entities, structure and processes which figure in scientific theories (the 'terms' of theories) rather than about the theories as such" (ref. [5], p. 12). We can remark also Planck's prudent optimism in connection with the possibility of scientific knowledge of nature, nevertheless opposed to different variants of detractors of Science.

One of the objections formulated against Science starts from the fact that, to describe the phenomena at a certain scale, -- in the world of elementary particles, or at the dimensions of galaxies – the scientists appeal to notions that don't have equivalents in the immediate reality, using a language which is inaccessible to the public and sophisticated (and expensive) instruments. Planck compares the instruments and the theoretical methods of the scientists of today with the scientific instruments and methods of the past, like the Galileo's telescope or old Mathematics (the Euclidean Geometry), which were also strange and new then for the public, but were accepted meanwhile by the society. The difference is essentially a quantitative one, being generated by the progress of the experimental technique and by the new domains of modern Mathematics, with a huge impact for Science as a whole and for human personality and society.

Planck's vision about Science has also important consequences for the relations between Science and Religion. The clarification of their relationship is considered vital for the human civilisation. The first question roused by the great German physicist is if a scientist can be a good believer (ref. [1], p. 157). The mission of Science to discover the laws of Nature makes the scientist sceptical about the miracles, which are, nevertheless, an integrant part of religious dogma. The relation between law and miracle is crucial for the problem of religious belief. On the other hand, to believe means to recognise entire dogma as true. Can a scientist remain a member of the religious community if he cannot accept the miracles, which contradict the laws of Science? Could we affirm today, in the era of Science "Credo quia absurdum"? Is a compromise possible between Science and Religion, which respects the scientific truth without hurting the religious feelings?

Before attacking the core of the problem, Planck tries to give an answer to two preliminary questions:

1) Which are the requirements imposed by Religion to its adherents?

2) What is the nature of scientific laws and which truths are considered indubitable by Science?

If, as seems to be, the religious feelings are inborn in the individual conscience, the Religion certainly has also a collective component, which tends to extend from person to person, community, nation, race, and towards universality. The religious spirit unites the people around symbols, myths, doctrines, which have also different external appearances: clothes, customs, rituals, shrines, holly places, icons, etc. Their diversity comes from the different historical, ethnic and cultural background. The common factor is, nevertheless, the existence of divinity cumulating anthropomorphic or personal features, from which follow such characteristics as: compassion, forgiveness, love, etc.

There are some symbols of religious worship that act directly on the imagination of the masses, giving a common understanding of deity. Some symbols are perennial, others can change in time. An example of the last type is offered by the angels, who, from the anatomical point of view, are absurdities, a fact stressed as early as in the Middle Ages, but angels inspired many artists and writers, mainly due to the symbols they represent. The biological absurdity mustn't prevent us to understand the idea transmitted through a symbolical message. Of course, this contradiction is used by the atheism, which ridicules the religious rites and symbols as being anachronisms. A reaction to this attack is to refine and restrict the religious symbols, to make them invulnerable at the erosion of belief in contact with Science. This is not always possible, because the symbols are necessary to Religion, as well as to everyday life. All symbols are human and they mustn't be confounded with the divinity, which they represent. Besides the acceptance of symbols, Religion asks the followers to accept the idea that the divinity has a real, objective existence; for the believer, the divinity doesn't disappear with himself and continues to rule independently of one believes in Him or not.

If scientists usually accept the first requirement -- and one explanation of this fact lies on the frequent use of symbols and conventions in the scientific activity -- the second one represents the point at which, in Planck's words, "minds part company basically and decisively". The second requirement of real, objective existence of divinity represents "a question which can never cleared up scientifically, by logical conclusions based on facts. The answer is solely and exclusively a matter of faith -- the religious faith." This requirement is the essential part of the creed that religion professes.

For analysing the acceptance of the second requirement from the point of view of Science, let us, together with Planck, to characterise the status of scientific knowledge. We must take into account that Planck wrote his essay on Science and Religion in 1937, but even then Planck's estimated that the laws of Nature were known to a measure capable to describe the phenomena from the physical world with a great degree of precision.

The observer (the man) is an actor in a paradox: he is located on a planet like a grain of dust in cosmos, but, on the other hand, with the help of Science he finds the universal laws and constants which regulate the course of entire Universe. This fact confers a privilege to man, that allows him to understand the order and construction of the world. Many known facts can be interpreted as proofs that the universe is rationally build. Following Descartes, Planck considers that the principle of conservation of energy and the law of minimal action, as expressing the economy of means in Nature, are clearly features of finalism and rationality. Further, Max Planck uses the Aristotelian concept of causes[5], considering our world as the result of the action of

[5]The problem of causality is central in the relations between Science and Religion (see, e. g. ref. [5], pp. 31, 45-55, 57-59, 158). Some of Planck's formulations hint to the so-called "top-down" causality, which allows to explain in Science the action of the superior levels of complexity on the "inferior" ones and in Theology the divine action in the world (ibid., pp. 52-55, 58-59, 60-61, 157-160).

"*causa efficiens*, which operates from the present into the future and makes the future situations appear as determined by earlier ones, joined by *causa finalis*, for which, inversely, the future -- namely a definite goal -- serves as a premise from which there can be deduced the development of the processes which lead to this goal (ref. [1], p. 179)[6]. Science presents, therefore, a picture of Nature in which the finalist activity of a universal conscience independent of the human existence is not excluded.

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For the believer and Religion, the starting point is the existence of God, for the scientist and Science, the existence of God is a final point. Religion offers God as given, while Science tries to define God by studying Nature. In Max Planck's vision, which is surprisingly near to critical realism -- as this current of contemporary thinking was defined by Arthur Peacocke (ref. [5], see, e. g. pp. 11-19) -- Religion and Science don't exclude each other, they complete each other. More than sixty years ago, Max Planck was a critical realist, inspiring the scientists, philosophers and theologians. It is a reason more to appreciate the great scientist.

Acknowledgements

The author is indebted to Professor Mircea Flonta for the discussion about Thomas Kuhn and to professor Gheorghe Nenciu for the common search of an explanation for Planck's wide range of interests in Science, Philosophy and Religion. Both we arrived at the conclusion that the high standard of classical studies in German educational system of Planck's time did offer him a solid basis for his rich intellectual development. A deep acknowledgement is due also to Professors Magda Stavinschi and Basarab Nicolesco and to Dr. Jean Staune for discussions and encouragement.

[6] The problem of causality in Planck's conception will be treated elsewhere (ref. [6]).

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Genesis and Evolution of Notion of (Physical) Law of Nature in 17th Century: Kepler and Descartes

Introduction

In Western thought the notion of law is used in the present time in three distinct fields: Religion (for divine or moral laws), Justice (for positive human laws) and Science (for physical laws, or laws of Nature), having respectively three quite different meanings coming, as we shall see, from a common root.

The divine, moral and juridical laws have in common the imperative character. The members of a certain community (confession, tribe, state) **must obey** these laws (commandments); the disobedience exposes the subjects to a punishment (divine, moral or juridical). Generally speaking,

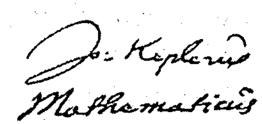
this category of laws is supposed to be very well known to all members of community through custom and oral tradition as well as through written religious and juridical texts or codes.

The laws or Nature are of different character, they apply to the rest of Creation, to the non-human world. Nature simply **do obey** to the physical laws. So, punishments are not conceivable in this field[1]. Another peculiarity of laws of Nature is their particular, incomplete, approximate and gradual knowledge. The active attitude towards the search for the laws of Nature and their use for human purposes is a fundamental Western characteristic which decisively contributed to the development of this part of world.

[1] The division between different types of laws was not clear even in this respect: punishments were inflicted to "guilty" animals, too. Some extension of divine law can be remarked at least for birds, as it can be seen from Giotto's frescoes dedicated to St. Francis, as announcing the present attitude towards the ecological problems.

The genesis of notion of physical law was determined by the existence of divine and juridical laws. The study of this development, its connections with the evolution of other fields of human knowledge until reaching the present stage is the aim of the present lesson.
Even if enforced by a terrestrial ruler and applied by his officials, the positive (juridical) law has a divine origin. This fact is illustrated in a very well known bas-relief, discovered at the beginning of this century, on which Hammurabi, the king of Babylon, receives the Law from Shamash, the God of Sun [1]. The Hammurabi Code is the earliest example of complete differentiation (branching) of juridical law from the divine one and can serve as a model to deduce how the notions of laws of Nature developed. If the apparition of the juridical law in its coded (written) form, separated from the divine law can be situated around 1750 BC, the genesis of laws of Nature is much more recent. The Hammurabi Code influenced the Bible, but in the Old Testament, the Lawgiver is also the Creator of the Universe. If the Hammurabi Code has a pure juridical character, in the Bible the commandments of God are religious, moral and juridical. It seems to be a step back from the complete separation of juridical laws done in the Hammurabi Code, but this mixing of different types of laws played a very important role for the future development of notion of law of Nature. If God had laid down the Law to be obeyed by humans, he must be also the author of a series of laws to be obeyed by the rest of his creation, from Earth to stars, from minerals to plants and animals. (See ref. [3], vol. II, p. 542 and ref. [2], p. 247.)
We have in this way a first idea about the unity of the universe: the world is the result of the unique act of divine creation and it is submitted to the laws of divine origin.
The rudiments of physical law can be retraced from Archimedes works, but the first laws of Nature near to the actual sense of this notion come from the 17^{th} century AC, being due mainly to Kepler, Galilei, Descartes, Hooke, Boyle and Newton. The present lesson takes in discussion the contribution of Kepler and Descartes in establishing the modern notion of law of Nature.

The law before the world:
Johhannes Kepler (1571-1630)



Johannes Kepler, one of the great scientists who made the seventeenth century scientific revolution, is universally known as the discoverer of the laws of planetary motion. Even if meanwhile science underwent another revolution, changing again our world view, a lot of old achievements remained important not only for the history of science,

but for the science itself. Between them, as a first approach to the celestial mechanics, are also Kepler's laws.
It is much easier to underline Kepler's revolutionary contribution to the foundation of notion of scientific law by developing a short historical presentation.
The Ptolemaic planetary system was a practical realization of the philosophical program which considered the uniform circular motion as being a perfect one and obligatory for celestial bodies. In conformity with the dominant philosophical conception of Antiquity, the Earth was situated in the centre of the universe, surrounded by celestial spheres. (As it is known, later on, the Christian theologians and writers officially took this world-view.)
This model originates in the work of Eudoxus from Cnidus **On speeds.** Eudoxus build there a system of geocentric and homocentric spheres as a first tentative to account for the apparent irregular motion of planets.
Eudoxus' model was merely a draft, which didn't even pretend to describe exactly the real sky. After the adoption of this model by Aristotle, one of his pupils, Calippus, who considered himself an adept of Pythagoras, developed it further into a very complicated set of rotating spheres, this time with precise aim to describe the motions of celestial objects.
In spite of being criticized by Hipparchus, the Aristotelian paradigm remained essentially unchanged until Ptolemy, who transformed it into a fully practical astronomical system, having the capacity to describe the main part of astronomical phenomena.
The innovation of Ptolemy was to suppose that a planet moves on a circle (called epicycle) with a mobile centre. The trajectory of the centre of epicycle was another circle (called deferent). The deferent played the role of a mean position of the planet. The Earth was not in the center of the deferent, but aside of it and the motion was considered uniform (with a constant angular velocity) in respect with a point, which was symmetrical with the Earth. The center of symmetry was the center of the deferent. This construction was necessary to

describe the variation of linear speed of planet and its retrograde motion.
Ptolemy broke the Aristotelian rule in two of its prescriptions: the Earth was not placed exactly in the center of the orbit and the uniformity of motion was not considered in respect with the Earth.
The Ptolemaic system was open; it had the capacity to "save the phenomena". When the astronomers observed a new motion, all that they had to do was to add new features to the system. This fact explains its durability for almost thirteen centuries. One can wonder what could be the astronomy today if, instead of adopting the Aristotelian dogma, Ptolemy would develop a heliocentric[2] model. But the conditional mode is not suitable for the history.
The Copernican system differs from the Ptolemaic one by the fact that the Sun is fixed and the Earth and all other planets move (not around the Sun, but around the centre of the deferent of Earth). So, from this point of view, the Earth is yet privileged, because its center of motion becomes the center of motion for all other planets. Copernicus wished to obey exactly to the antique prescription of the regular motion, from which Ptolemy departed. He made the Earth to move uniformly in respect with the centre of deferent. In this sense, Copernicus was even more Aristotelian than Ptolemy. For the rest, Copernicus kept entirely the Ptolemaic celestial geometry and made it more complicated. To take into account several planetary motions, he was forced to introduce new small epicycles. It was the price for his return to the dogma of uniform motion. (The usual graphical representations of Copernican system show the Sun in the centre and the planets around it, evolving on concentric circles. In this way, the essence of the system remains hidden behind an oversimplified image.)
The Danish astronomer Tycho Brahe had his own ("Tychonic") system, with the Earth fixed and the Sun rotating around the Earth and

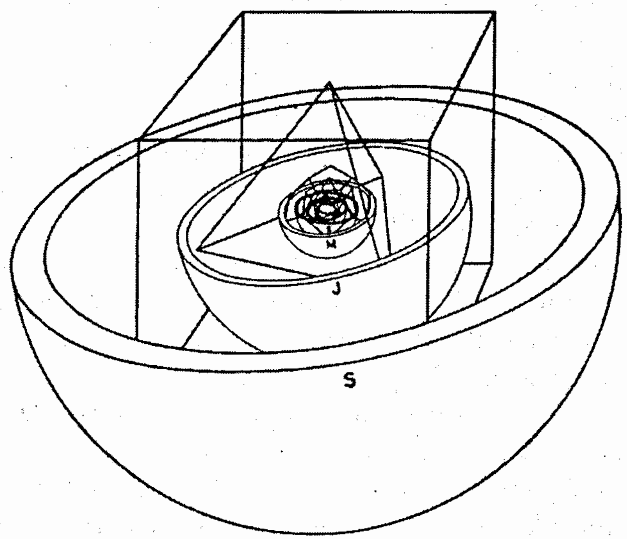
[2] The correct term is heliostatic, because, as one can see, Sun doesn't occupy the geometrical centre of orbits.

carrying with it Mercury and Venus. Brahe's system was a compromise between the Ptolemaic and Copernican systems.
This was the general situation in the astronomy at the beginning of the year 1600, when Johannes Kepler arrived in Prague to start his work as Tycho Brahe's assistant[3]. It was not only the meeting of two great scientists and of two opposite characters (the meeting of the century, as it was called by Arthur Koestler, [4]), but also a happy encounter of the experiment with the theory.
Tycho Brahe, then near to the end of his life (he will die next year), was the greatest observational astronomer after Hipparchus and the owner of an invaluable treasure: the exact and systematical observational data gathered all along his scientific life. He hoped that Kepler would prove theoretically the "Tychonic" system.
Johannes Kepler, then at the prime of his scientific activity, was eager to start his quest for an ordered and harmonical model of the universe, which he thought to be hidden in his master's astronomical data.
Two dominant ideas characterized Kepler: his firm, instinctive adherence to Copernicanism, dated from his years at the Tuebingen University and his conviction that the mathematics can reveal the secrets and the beauty of nature. Both these ideas were aprioristic and, at least for Kepler, they had a clear metaphysical origin.
Kepler attributed to the Sun magical properties; so, he was satisfied with its position in the Copernican theory. Kepler's concept of mathematical beauty of Nature (the harmony of spheres) was even older than Platonism, so frequently invoked in connection with Kepler. His conception was mainly a revival of Pythagoras and of his mystic of numbers.
With this philosophical background and with his knowledge of mathematics, Kepler represents the best example of a scientist hunting a chimera and discovering, as a byproduct, the true laws of Nature.

[3] Tycho Brahe was then the Imperial Mathematician of Rudolf II of Hapsburg. Kepler was appointed to this function after Tycho's death.

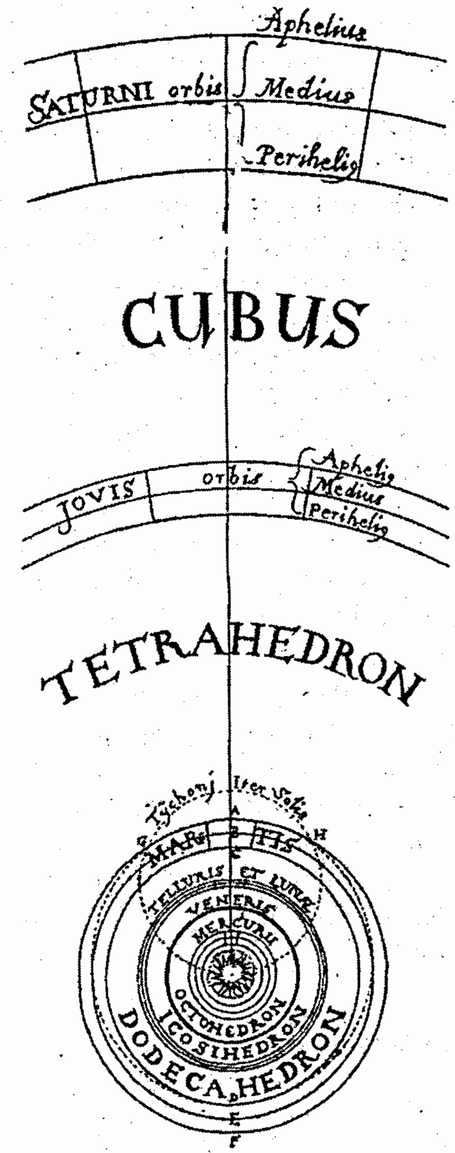
The main result of Kepler's activity consists in a radical departure from the Copernican system, from which he conserved only the heliostaticity and the motion of Earth. Kepler removed the cumbersome geometrical structure of wheels in wheels inherited from Ptolemy. Instead of it, Kepler introduced for each planet a simple elliptical trajectory, having the Sun in one of foci in the ellipse.
The second dogma of Ptolemaic astronomy was shattered too, the planets moving now with a constant areolar velocity, in respect with the Sun. This motion allows a variation of linear speed along the trajectory. In this way, Kepler was more Copernican than Copernicus himself, who didn't use the Sun as a reference point.
Known as the first and the second of Kepler's laws, these two statements, published in 1609 in his book **Astronomia Nova,** were elaborated in a totally different way than the previous astronomical axioms. Kepler's deduction of laws of solar system is a unique exploit in History of Science. Kepler was conscious about his adventurous way toward the truth and, fortunately for his readers, described the details of his intellectual journey. He justified this confession writing in **Astronomia Nova** that the path to the truth is as interesting as the truth itself. Here, Kepler's path to the truth will be presented with the aim to understand what meaning he gave to the notion of law.
Kepler's first book, **Mysterium Cosmographicum,** published in 1596, contains his first idea about how the solar system is organised. He wanted to obtain a rule for the intervals between the planetary trajectories and believed that it must be found somehow from geometrical considerations. He wished also to have an explanation why the planets are exactly six (Mercury, Venus, Earth, Mars, Jupiter, Saturn).
After trying some combinations with regular polygons, Kepler went to regular solids, known from Euclid as being only five. This number attracted him because six planets have five intervals between them, while the number of regular polygons is infinite. So he tried to make combinations with spheres and regular bodies, hoping to reproduce the known astronomical idea about intervals. He inscribed each orbit in a

sphere and inserted between these spheres the five regular solids, so that each solid was circumscribed to the smaller sphere and inscribed in a greater one. The (arbitrary chosen) order of the solids was the following (from Mercury to Saturn): octahedron, icosahedron, dodecahedron, tetrahedron, and cube. Even so, it was quite difficult to obtain the correct sequence of the intervals and some compromises were necessary, like making the spheres thick, to account for the aphelion and perihelion of planets.



After a time, Kepler renounced at this model, but the idea of planetary intervals will germinate until guiding him to the third "law", which connects the distances of planets to Sun with their periods[4].

[4]Even so, Kepler published twice his **Mysterium Cosmographicum**, the second (revised) edition dating from 1621.



After this first failure, Kepler had more luck when Tycho Brahe gave him Mars to study. Mars has a relatively large eccentricity, passes quite near to Earth and allows a better determination of its orbit from earlier observations. Working with Mars, and based on Tycho's data, Kepler was able to improve considerable the predictions of Mars longitudes (ten times better than the previous astronomers). He didn't succeed, however, to calculate exactly the distances. So he went back to epicycles, this time generating an egg-like orbit, which he disliked.

Finally, starting from considerations connected with a pretended magnetic interaction[5] between Sun and planets, Kepler arrived to the ellipse as a planetary orbit, which fitted well the observational data, including the famous eight minutes of arc discrepancy which so exasperated him before. This achievement was not possible before Kepler's innovations in calculating the relative positions of Mars and Earth, as well as other technical novelties. The detailed story of the discovery is very complicated and, in course of it, Kepler found once the ellipse, but dismissed the hypothesis (see **Astronomia Nova,** [8], vol. 3, chapter LVII.).

When Kepler realized that the right trajectory is the ellipse, he wrote:

> *I could not find why the planet would rather go on an elliptical orbit. Oh, ridiculous me! As if the libration[6] on the diameter could not also be the way to the ellipse. So this notion brought me short, that the ellipse exists because of the libration.*
> *... With reasoning derived from physical principles ageing with experience, there is no figure left for the orbit of the planet except a perfect ellipse[7].*

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[5]Like Galileo, Kepler studied Gilbert's work on magnets.

[6]The libration is a small, but perceptible variation of dimensions of the celestial object due, for example, to the variation of its distance.

[7]Quoted by Owen Gingerich in Vistas in Astronomy, vol. 18, p. 277. The complete quotation is:

O me ridiculum! Perinde quasi libratio in diametro non posset essere via ad ellipsin.

ASTRONOMIA NOVA
ΑΙΤΙΟΛΟΓΗΤΟΣ,
SEV
PHYSICA COELESTIS,
tradita commentariis
DE MOTIBVS STELLÆ
MARTIS,
Ex obſervationibus G. V.
TYCHONIS BRAHE:

Juſſu & ſumptibus
RVDOLPHI II.
ROMANORVM
IMPERATORIS &c:

Plurium annorum pertinaci ſtudio
elaborata Pragæ,

A S. C. M.tis S. Mathematico
JOANNE KEPLERO.

Cum ejusdem C. M.tis privilegio ſpeciali
Anno æræ Dionyſianæ cIɔ Iɔ c IX.

It is evident that Kepler didn't stress the importance of his "laws", nor called them by this word. The reader of **Astronomia Nova** can much easier find “the first Kepler’s law” from the summary of chapters, (**Argumenta capitum, caput LIX**): … *orbitam igitur Planetae esse Ellipticam,* than from the text itself. Even if “the physical principles” (*principiis Physicis*) were not correct, these ones, together with the necessity to fit the orbit to the data finally drove Kepler to the ellipse. The same chap. LIX contains “the second Kepler’s law”, hidden between the geometrical properties of ellipse, demonstrated following the methods of Apollonius and Archimedes.

Both these laws are better exposed in his work **Epitome Astronomiae Copernicanae,** published in 1618-1621, [8], vol. VII. The **Epitome** is a handbook of astronomy, where the astronomical knowledge is presented as a series of questions and answers, or as short ennounces followed by demonstrations or explanations. Kepler starts with expounding the basis of Copernican astronomy, adding his own contribution to the development of this field. The first law is contained in the title of a paragraph, **De figura orbitae,** op. Cit., Liber quintus, pars prima, III, p. 372, being so easier to identify.

In **Epitome** one can also find subjects treated before in **Astronomia Nova** and **Harmonice Mundi,** reproduced or slightly modified. Some of them are accompanied by Kepler’s own critical comments. A few pages later, (ibid., p. 378), one find the second law, enounced synthetically: ... *area pro mensura temporis constituitur,* with the mention that to unequal arcs of the ellipse, at equal times, there are equal arias covered by the radius of the planet. Kepler modifies his demonstration from **Astronomia Nova,** considering it too obscure.

The third law is presented also in **Epitome,** in book IV, second part, IV, p. 307, under the title **De causis proportionis periodicorum temporum,** as a proportion of segments. The interpretation of this proportion is not easy and the editor, Max Caspar, made a comment to show its meaning.

The most important moment of Kepler’s intellectual quest for the laws was the supposition that the Sun must be the physical origin of planetary motion. Indeed, Kepler was interested to discover the physical explanation of the solar system, as it can be seen from the

complete title of **Astronomia Nova: The new astronomy based on physical causes of the Celestial-physics.** In the same sense, the **Epitome** contains the affirmation that the Sun is the cause of planetary motion. The main question of Book IV, 2, III is:

> *Quibus causis adduceris ut Solem facias caussam moventem, seu fontem motus Plenetarum?*

Later on, Kepler considers the rotation of Sun (proved by the motion of sunspots) as the true cause of motion of planets.

It is interesting that both findings from **Astronomia Nova** were considered by Kepler only as byproducts of his activity devoted mainly to put into evidence the cosmic harmony.

For Kepler, the notion of harmony was not only a metaphor, but a real working hypothesis, which took mathematical form and exhibited aesthetical features[8]. If previously he connected the intervals between planetary spheres with the regular polyhedra, in **Harmonices Mundi,** (a book which appeared in 1619), the planets are supposed to emit sounds. Kepler connected the velocity of planets with the pitch of the sound and obtained a kind of melody for each of them. As the velocities are different for aphelion and perihelion, the corresponding notes of planetary melody are also different. A planet as Venus, with an almost circular orbit and, consequently with an almost constant angular speed, will emit a constant humming.

[8] Theoretical Music (as a science of harmony) was then a part of mathematics.

Ioannis Keppleri

HARMONICES MVNDI

LIBRI V. QVORVM

Primus GEOMETRICVS, De Figurarum Regularium, quæ Proportiones Harmonicas constituunt, ortu & demonstrationibus.

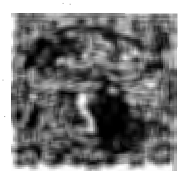
Secundus ARCHITECTONICVS, seu ex GEOMETRIA FIGVRATA, De Figurarum Regularium Congruentia in plano vel solido:

Tertius propriè HARMONICVS, De Proportionum Harmonicarum ortu ex Figuris; deque Naturâ & Differentiis rerum ad cantum pertinentium, contra Veteres:

Quartus METAPHYSICVS, PSYCHOLOGICVS & ASTROLOGICVS, De Harmoniarum mentali Essentiâ earumque generibus in Mundo; præsertim de Harmonia radiorum, ex corporibus cœlestibus in Terram descendentibus, eiusque effectu in Natura seu Anima sublunari & Humana:

Quintus ASTRONOMICVS & METAPHYSICVS, De Harmoniis absolutissimis motuum cœlestium, ortuque Eccentricitatum ex proportionibus Harmonicis.

Appendix habet comparationem huius Operis cum Harmonices Cl. Ptolemæi libro III. cumque Roberti de Fluctibus, dicti Flud. Medici Oxoniensis speculationibus Harmonicis, operi de Macrocosmo & Microcosmo insertis.



Cum S. C. Mtis. Priuilegio ad annos XV.

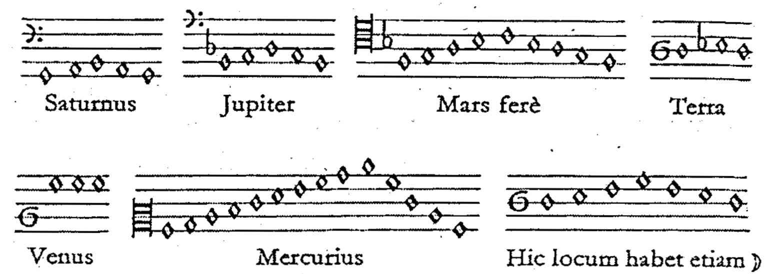
Lincii Austriæ,

Sumptibus GODOFREDI TAMPACHII Bibl. Francof.
Excudebat IOANNES PLANCVS.

ANNO M. DC. XIX.

The well-known historian of astronomy, J.L.E. Dreyer, ref. [5], transcribed in modern musical notation the melodies of planets. So, the Pythagorean Music of Spheres, audible for the initiates only, revived from Kepler's **Harmonices Mundi.** The result was a consonant music,

a real concert of planets, grace again to some manipulation of numbers made by Kepler.



The "third Kepler's law" followed quite simply from the accumulated data, and Kepler seized it from his huge number of calculations and comparisons. This "traditional" description of Kepler's finding[9] is criticized by some historians of science, like Owen Gingerich, ref. [7]. Kepler already in Mysterium Cosmographicum formulated the problem of finding a relation between the periods and distances and Gingerich asks why it took so long until Kepler found a quite simple law, especially if compared with the two first laws. In contrast with his unusual openness, Kepler didn't offer so many details in connection with his third law and this fact makes the answer to this question more difficult. In **Mysterium Cosmographicum** Kepler introduced the notion of driving force of Sun, inverse proportional with the distance. From this supposition, Kepler obtained a (false) proportionality for the periods (with the square of distance), which, for the moment, was acceptable for him.

The correct relation (the cube of the mean distance of planet to Sun is proportional with the square of the period of its revolution), was obtained only after some physical considerations about the amount of matter in planets and also after using the "archetypal reasons" (in fact, pure arbitrary suppositions) which allowed a correct result, sustained

9 Taken mainly from Kepler's own confessions.

by the comparison with the observational data. It is important to mention that Kepler didn't give much importance to his third law, his main interest being directed to the world harmony.
The first Kepler law, stating the elliptical trajectory of planets, differs from the previous Copernican and Ptolemaic assumption not only in the form of the orbits but also in the way of introducing it in the corpus of laws. In both pre-Keplerian systems, the form of the orbits (the circular one) was postulated, while Kepler selected the ellipse also from observational reasons. One ellipse with small eccentricity is near to a circle, so it can describe the orbit of Venus, for example. The circle is an aprioric orbit in the first two systems, while the ellipse is an experimental (a posteriori) finding in Kepler's system.
The third law is exposed in a form of a ratio, like other laws known in that time (see the section dedicated to Galilei). That means that in the mathematical expression of the law no constants are present; they are simplified by the dividing operation, like in geometry.
The second law has a geometric origin, too, but its mathematical form is an absolute novelty, a revolution in the notion of law, which opened the perspectives, to be fully understood only after the apparition of mathematical analysis. The law of areas is limited to the elliptical (and circular) orbits, but it played a very important role in Newton's law of gravitation.
The analysis of the tortuous emergency of Kepler's law reveals some treats of the euristic process which characterize Kepler's personality. Two of them, the mathematical treatment of observational data and the importance given to the Sun, were stressed at the beginning of this section. Both can be found in different degrees at other contemporary scientists, too.
A typical trait for Kepler alone is the art of approximation. Some of Kepler's commentators accused the German scientist of treachery or cheating. Of course, the results which Kepler obtained were far from being exact. Nevertheless, he knew when to stop, to close the direction of his research and to take another path. So happened with the egg-

shaped orbit, the rejection of which was motivated also by aesthetical reasons.
In other occasions, the motivation was strictly mathematic one, like when he renounced at he nested regular polyhedra. First, he "cheated" making the spheres thick. Even with this departure from geometrical exactness, followed by other "cheatings", the system of spheres and polyhedra didn't fit with Tycho's data and the accumulation of discrepancies made him to abandon the model.
One can better understand which great difficulties stood in front of Kepler when he started to look for the laws if comparing them with their modern generalizations.
The first generalized Keller's law admits all conic curves as orbits: circle, ellipse, parabola and hyperbola. The first two were also present in Kepler's first law, taking into account that the circle is the limit of an ellipse when its eccentricity becomes zero. The parabola was studied by Galilei in connection with the motion of projectiles, but this kind physics done on earth was not yet recognized as being an aspect of Kepler's problem.
The second law remains essentially unchanged.
The third one becomes:

$$\frac{T_1^2}{T_2^2} * \frac{m_0 + m_1}{m_0 + m_2} = \frac{a_1^3}{a_2^3}$$

where T_1 and T_2 are the periods of two planets, m_0, m_1 and m_2 are the masses of the Sun and of the planets and a_1 and a_2 their major semi axes.
If the mass of planets is negligible in comparison with the mass of Sun, the above formula becomes Kepler's third law.
All three generalized Kepler's laws are deduced for the case of absence of perturbations coming from other planets, an assumption which simplify very much the description of planetary motion. The comparison of the real trajectories with the calculated ones allows putting into evidence the perturbations, this method being used later to predict the existence of planets like Neptune and Pluto.

The Kepler's laws had practical consequences, too. After a period of "hibernation", from which they were awakened by Newton's **Principia,** the laws were used to predict the astronomical phenomena until the next century, inclusively. The **Tabulae Rudolphinae,** (1627) elaborated by Kepler with Tycho's data and containing the location of more than thousands stars and extended planetary tables, had the same lifetime. Even a direction of research like the geometrical speculations from **Mysterium Cosmographicum** had followers (Titus and Bode) who looked for empirical formulae to reproduce the sequence of planetary distances to the Sun, ref. [9]. This direction of research continues even today.

In **Harmonices Mundi,** book III, there is a part called **Digressio Politica,** were Kepler tried a parallel between Geometry and Justice. Here, the word law (lex, legis) can be found in a juridical context. Was Kepler aware also of the existence of physical laws? Following the reasoning of Needham, merely based on linguistical reasoning, [3], vol. II, chap. 18, **Human law and laws of nature,** the fact that Kepler didn't call his laws with this word pleads for a negative answer to the last question. Nevertheless, in **Epitome,** p. 332, Kepler uses the word law in a clear physical sense:

Quae sunt huius celeritatis et tarditatis leges, et exempla?

Kepler writes here about the laws of motion of the extremities of a lever in equilibrium, when trying to explain some details of planetary motion. The longer side of lever will move with celerity, the shorter one will be retarded, as covering a smaller distance in the same time. It isn't a casual reference; in the same context, of planetary motion, and in the same **Epitome,** p. 338, Kepler uses again (two times) the word law with the meaning of physical law. The first mention refers to the laws of planetary motion *leges motuum* imposed by the nature *a natura sunt institutae.* The planets, writes Kepler, move on their precise orbits in free ether *in libero aethere,* under the influence of two laws, one of attraction, other of repulsion, comparable between themselves (comparatae leges); the orbit is the result of their permanent equality.

These examples contradict Needham's affirmation about Kepler, op. cit., p. 540:

There's no doubt that the turning point occurs between Copernicus (1473 to 1543) and Kepler (1571 to 1630). The former speaks of symmetries, harmonies, but never in any place of laws.

On the next page, Needham, writes:

By a remarkable paradox, Kepler, who discovered the three empirical laws of the planetary orbits, one of the first occasions on which the laws of Nature were expressed in mathematical terms, never himself spoke of them as laws, though he used the phrase in other connections. Kepler's first and second "laws" given in **Astronomia Nova** *of 1609, are paraphrased in long expositions, the third, published in* **Harmonices Mundi** *(1619), is called a "theorem". Yet he speaks of "law" in connection with the principles of the lever, and in general uses the words as if it were synonymous with measure or proportion.*

To sustain his statement, Needham quotes Zilsel, ref. [2], but in the Zilsel's article no reference is made to the Kepler's *leges motuum,* nor to the last two places in **Epitome** were Kepler used the notion of law, quoted in the present work. Kepler doesn't use the word "law" in direct "connection with the principles of lever", as affirms Needham, but in connection with the motion of extremities of it.

Following the note **d** in Needham, op cit. P. 541:

> *... Kepler, like Bruno, conceived of planets as partly animate, and rised the question of "whether the laws are such, that they can probably be known to the planet".*

Here, Needham and Zilsel, whom Needham cites, seem to not be aware of Kepler's evolution which started, indeed, with the phase of *partly animated* planet from **Mysterium Cosmographicum.** In **Astronomia Nova,** (Book III, chap. 39), Kepler decides to renounce at the soul of planet. The reason for this decision is the difficulty with which the soul will be confronted when it will have to calculate the orbit followed by the planet. Later, in **Epitome,** (see p. 229), Kepler went to a deterministic and objective conception about the motion of planets, rejecting the intervention of planetary intellect and criticising his previous position from **Mysterium.** This new Kepler's position, exposed in different contexts in **Epitome** is clearly sustained:

> *Quas tradis causas motus in latitudinem?*
> *Nec Sol planetis causa est, nisi remota huius deviationis ab Ellipticae plano, nec Mente planetis ad hoc opus est, nec supra refutata substuctione solidorum orbium... sed formatio aliqua ipsorum corporum planetariorum sola sufficit at detorquendas ed Eclipticam, eorum orbitas.* (Liber quarto, pars tres, IV, **De Motu Latitudinis,** p. 343.)

Here, Kepler negates the pretended mental cause of planetary motion, or his (already rejected) theory of five regular solids. The only cause resides in the corporeal structure of planets themselves. The same statements about the corporal nature of action of Sun can be found in Epitome, p. 299:

> *...corporalis est virtus, non animalis, non mentalis.*

The problem why Kepler didn't use the word law for his laws remains open. Here it was offered only a hint (the secondary interest given by Kepler to his laws, in comparison with his assumed task, to demonstrate the Harmony of Creation). The study of this subject will be done elswhere.

The structure of other Kepler's works, like **Dioptrice,** ref. [8], vol. IV, have a structure similar with Euclides' **Elementa,** with *Definitio,* definition, *Axioma,* axiom, *Propositio,* proposition, *Problema,* problem, etc. This style of presentation is common for many contemporary works; it will be used many years, including the last part of the XVII century, in Newton's **Philosophiae Naturalis Principia Mathematica.**

Kepler's laws show a total independence from the point of their departure, even when the hypothesis was a mythic one. From this point of view, Kepler is a modern scientist. His own way to scientific truth represents a difficult, but successful transition from the old science to the new one, not only of the XVII-th but also of the next century. Often it is difficult to understand in which way went Kepler to his discoveries: by induction, by (aprioristic) hypothesis, by pure empiric

or intuitionistic procedures, etc. Most probably, he used all these methods (see [6]).

Kepler was aware of the historical limitation of knowledge but wanted to push its limits as far as possible. He wrote: *I could ignore the core of the matter – and avoid the trouble of thinking about it... but the lack of courage is the death of philosophy... Let us live and dare to try!*

The theoretician of law:
René Descartes (1596-1650)

In his famous **Discourse on method**[10], Descartes allows three different meanings for the notion of law. The first two correspond to the old acceptions of divine and juridical laws. In the third chapter of the **Discourse** one may read:

The first [maxim of the moral code] was to obey the laws and custom of my country, firmly preserving the religion[11] *into which God was good enough to have me instructed from childhood...*[12], [10], p. 45.

One have presented here (implicitly) the divine law, as a dominant of the philosopher's soul and (explicitly) the juridical law.

The Discourse is not a treatise, but merely an outline of Descartes' intentions, a kind of life program. Being written in French and in a non-technical manner, this book strongly influenced large circles of public. From this point of view, the **Discourse** played the same role for Descartes as the **Commentariolus** for Copernicus, ref. [11]. Both

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[10] The comple title is: **Discours de la Méthode pour bien conduire sa raison et chercher la Vérité dans les sciences. Plus La Dioptrique, Les Météores et La Géometrie, qui sont les Essais de cette Méthode,** Leyden, 1637.

[11] Besides being a religious man, here Descartes writes for **captatio benevolentiae** of the Jesuits, whom he recognized the leadership of catholic intellectual elite. It is also to be remembered that Descartes published this book four years after the trial of Galileo.

[12] Descartes entered a Jesuit college in 1606 and stayed there until 1614, when he was eighteen.

scientists were better known from these two programmatic or resumative works than from their fundamental treatises published later. After a few pages, [10], p. 61, Descartes introduces the new notion of law of Nature:

I have observed certain laws which God has so established in nature and of which he has impressed such notions in our souls, that having reflected on them sufficiently, we cannot be in any doubt that they are strictly observed in everything which exists or which happens in the world. Then, by considering the series of these laws, it appears to me that I have discovered many truths more useful and more important than anything I had learned before or hoped to learn.

It can be remarked that in Descartes' opinion God not only *established laws* to the Nature, but also *impressed such notions* in man's intellect. Such **build in** human characteristic encourages the endeavor of discovering the laws of Nature by methodic reflection. If the potentiality of discovering the laws was offered to men by God, the method of finding them is developed by Descartes in his **Discourse.** One must, nevertheless, consider carefully Descartes' conception of cognoscibility of laws. Almost in the same time with the apparition of the **Discourse,** its author wrote a letter to Marin Mersenne (May 17th, 1638), cited in ref. [13], p. 12:

> *Exiger de moy des demonstrations Geometriques en une matiere qui depend de la Pysique, c'est vouloir que je fasse des choses impossibles.*

This last point of view is difficult to reconcile with the more optimistic one expressed in the **Discourse.**

It is not so clear where looked Descartes more to observe the laws, in Nature or in his soul. An answer can be obtained by looking in his treatises, which will be done later in this section. For the time being, one can see that the action of laws is described by Descartes as being (from a certain moment) somehow independent from the starting point and (to a certain extension) from the Creator himself. Once imposed to the material world, the laws will perform alone their task, putting an end to chaos and transforming it to cosmos.

This point of view was strongly criticized by Robert Boyle. He disagreed especially with Descartes' affirmation that matter can be in independent motion. His argument was that matter is not so wise to move by itself. Boyle denied the application of laws of Nature to all inanimated bodies (**res extensa**) by the same argument. The law was stated mainly for the minds (**res cogitantes**). Such a limitation of action of laws shows an incomplete elaboration of notion of law of physics and an interference between juridical laws and laws of Nature. Expressed by a physicist who was actively involved in finding the laws of Nature, these opinions are a step back from the more radical point of view of the author of the **Discourse.** We will come back to this subject later on.

Certainly, Descartes' picture of the universe doesn't coincide with the full mechanistic world view of Laplace, in which there is no place for God. Moreover, Descartes' universe need a kind of supervision of God, a *preserving action* which, together with the free action of laws monitorize the process of Nature. Nevertheless, in comparison with other notions proposed by the French philosopher, the *preserving action* is quite abstract and will evolve in a conservation principle (see below).

Descartes performs even an **Gedankenexperiment** on the full scale of Nature, to demonstrate how the laws act, [10], pp. 62-63:

> *...if God were now to create, somewhere in imaginary space, enough matter to compose [a new world] and if he were to agitate diversely and confusedly the different parts of this matter, so that he created a chaos as disordered as poets could ever imagine, and afterwards did nothing than to lend his usual preserving actions to nature, and let her act according to his established laws. [...] After this, I showed how most of the matter of this chaos must, in* accordance *with these laws, dispose and arrange itself in a certain way which would make it similar to our skies...*

If God will repeat the act of creation, his laws will lay another world which will be identical with the present one. More than mechanics, this picture suggests the thermodynamics of reversible processes and even an alternative cosmology. Even if the actual structure of the world is to be destroyed (by agitating *diversely and confusedly the different parts of this matter)* the actual world would be recreated. The optimistic idea about the rebirth of the universe is associated with an equally optimistic idea of deciphering the action of the laws on material things (**res extensa**):

> *Their nature is much easier to grasp, when one sees them being fully made from the start.*

Descartes seems to recognize in this way the necessity of knowing the initial conditions for the description of the processes in the nature.

The qualitative treatment of the gnoseologic problem includes *proving effect by causes, and demonstrating from what elements and what way nature must produce them.*

Descartes did not limitate himself to the qualitative aspect of the knowledge. He was convinced that the complete knowledge of Nature can be reached only with the help of Mathematics and he invented new mathematical tools which were to be used by the following generations with the same aim to understand Nature.

Descartes tried himself to discover some of laws of Nature; accordingly to the programme exposed in his **Discourse**, he started with the study of light. By the time when he decided to undertake this research, the Optics was a quite developed field of Science with a long history, both in physical aspects, as well as in the problem of light perception.

Descartes'work in this field, the **Dioptrics**, is merely a systematization of facts already known, than an original one. Its main achievement is to establish a high standard of a scientific treatise. The most important statement made there is the law of refraction. Descartes doesn't use here the word of "law". Even in the **Discourse** the term of "law" is not fully adopted by the author, who oscillates between "law" and "rule". He writes: *...according to the rules of mechanics which are the same as rules of nature,* [10], p. 72. Previously, he used the term "law" in the same context.

It is a dispute if Descartes discovered the law of refraction independently, or if he was influenced by the Snell's unpublished paper on this subject. Here, this fact is of secondary importance. The **Dioptrics** has another merit: it proves that the author was ready to look for the laws of Nature also in Nature, and not only in his soul. To the same conclusion on arrives reading the **Meteors.**

The law of refraction was a starting point for another research done in the **Meteors**, where Descartes proposes an explanation for the rainbow. Assimilating the rain drops with small prisms, which is a quite reasonable assumption, he succeeds to explain some of the features of rainbow.

The treatise where the notion of law is further developed, **Principia Philosophiae**, was published in 1644 in Amsterdam. This book, based on the mathematics, represents a complete exposition of his philosophical system, starting with the act of creation. After Descartes, the created world consists of two class of things **res cogitantes** (minds) and **res extensae** (bodies). The physical world is made by bodies, which are characterized by their spatial extension. The space is filled with matter, the void cannot exist.

The bodies move in space and their motion is conceived like a transport from one place to another, from one body to another and its cause is the (infinite) power of God. The idea about God as a creator of matter and as a final cause of motion leads Descartes to a kind of conservation laws of matter and of motion. If God, says Descartes, started **ab initio** with to move the matter which he created, then he conserves its motion, like he conserves the matter, so that one finds the same amount of both of them as at the beginning.

These statements about matter and motion, which are preliminaries of conservation laws, are called by Descartes principles. Even in the present times the statements about the conservation of matter and of energy are called principles, as having a primordial importance in the hierarchy of laws of Physics.

From the principles, Descartes deduces the three laws of mechanics, called by him the laws of nature. They are, in fact, two statements of

the principle of inertia enounced in a different manner than the modern synthetic formulation, plus one law about the transmission of motion. In the Descartes' philosophical conception, nature was reduced to (mechanic) motion of bodies. From this point of view, the motion was the most important phenomenon which could explain the world.
The first law states that a body at rest remains so until some agent changes it and that a body in motion continues its motion if nothing impedes it. Descartes recognizes the necessity of a moving force exerted on a body to permit its motion in a resistant medium.
The second law treats with the trajectory of motion: the bodies have the tendency to move in straight line. The circular motion needs forces to keep the body in the trajectory. These statements are in open contradiction with the Aristotelian dogma and quite known at the date of their adoption by Descartes. His contribution is mainly to systematize the existent knowledge. (For a comparison with Galilei's principle of inertia, see [14], Appendix B.)
The third law deals with the collision of bodies, but the imprecision of notions, the pure geometrical conception of motion, as well as the absence of the concept of mass forbade a true physical treatment of *exchange of motion* between bodies.
Descartes goes further, elaborating seven secondary "rules" treating the problem of transmission of motion from one body to another.
Some of his deductions are erroneous and the vulnerability of his system is due mainly to Descartes' conception about the relative euristic value of logical deduction and experiment. Without rejecting the last one, Descartes doesn't give to the experiment the decisive role of ruling out the theoretical statements. He reduces the experiments to a formal inquiry, having a minor status in comparison with **a priory** findings. Practically, with a few exceptions, Descartes reduces the Physics to mathematical principles. The errors from Descartes "rules" were evident even in his time and easy to discover through simple experiments (see, for example, [12], p. 163).

This fact has as a consequence the impoverishment of the notion of law of Nature and the loss of the possibility of experimental verification.
Descartes is, probably, the inventor of the expression of "law of nature", which he used in his Natural Philosophy as one of main notions. His greatest merit was to connect the new notion with the mathematics. He wrote: *Apud me omnia sunt mathematica in natura.* It was a common idea for many scientists of the same period[13] but at none of them was so strongly expressed as at Descartes. He extended the notion of mathematics to be used in the study of Nature from Geometry to Algebra, preparing the apparition of the modern notion of law as a functional dependence between physical variables.
From principles to laws and from laws to rules there is a hierarchy of statements, which begins with God, to descend to bodies. Descartes' laws of Nature are deterministic, causal and repetitive. They are keys to understand the Nature.
The mathematization of notion of law of Nature performed by Descartes has nevertheless one indesirable feature: as a mathematical relation, the physical law must involve exact values of variables, which is not the case in the physical world, where the measured values can be only approximate.
This fact was correctly understood by another great scientist of the 17th century, who was a complementary thinker in respect with Kepler and Descartes. His name is Galileo Galilei.

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[13] Centuries before Descartes. Roger Bacon (the **Doctor Mirabilis**) wrote almost in the same key: *Et harum scientiarum porta et claves est Mathematica.*

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