

FROM THE HISTORY OF PHYSICS

PACS numbers: **01.60.+q, 01.65.+g**

450th ANNIVERSARY OF THE BIRTH OF GALILEO GALILEI

"Galileo was amazingly endowed with a gift of... inculcating scientific truth" *

R N Shcherbakov

DOI: 10.3367/UFNe.0184.201402c.0153

Contents

Abstract. **Since centuries ago, when he came to the fore as a mighty figure in Enlightenment science, Galileo Galilei has been admired and respected not only for supporting Copernican theory and laying the foundations of mechanics and physics; and not only for his unique ability to disprove arguments against the new science and the new worldview; but also for his civic courage in defending his discoveries and convictions, a crucial quality for anyone who opposes outdated views and ideas.**

1. Introduction

Galileo Galilei, the genius Italian scientist, educator, and proponent of new science and scientific thinking, greatly contributed to the development, promotion, and defense of that science and thought against scholastic ideas of his time. The discoveries made by Galileo laid the foundations on which classical mechanics and physics have evolved.

His unique gifts and abilities are equally admired and respected by both humanities scholars and natural science enthusiasts. Everyone finds in Galileo's creativity and demeanor that innermost self which brings us closer to the ideals of intelligence and humanism. That is why so much attention is still focused on this personality giving rise to hundreds of thousands of essays, books, and articles dealing with his work.

Galileo Galilei
(15.02.1564 – 8.01.1642)

Of special interest for the physics community is the work on the history of science, with an analysis of the main aspects of Galileo's research by such leading physicists as S I Vavilov [1], A N Krylov [2, pp. 152–155], and V A Fock [3], published in *Physics-Uspekhi* in the 20th century, and by historians and philosophers of science (B G Kuznetsov, A V Akhutin, V S Bibler, and V S Kirsanov [4–8], to name but a few).

* A quote from S I Vavilov's article, "Galileo in the history of optics" [1, p. 584].

R N Shcherbakov Pyarnuskoe shosse, d. 125a-29, 11314 Tallinn, Esthonia
Tel. (372) 674 86 80
E-mail: robertsch961@rambler.ru

Received 25 September 2013, revised 8 January 2014
Uspekhi Fizicheskikh Nauk **184** (2) 153– 160 (2014)
DOI: 10.3367/UFNr.0184.201402c.0153
Translated by Yu V Morozov; edited by A Radzig

Clearly, the personality characteristics of a scientist operate as valid predictors of his influence on science, general culture, ideology, and the public mind. This influence is especially apparent in the periods when many people begin feeling disappointed with former ideals and values, while new ones have not yet taken hold and become major parts of popular consciousness. Galileo's life fell in such time.

His creative activities proceeded along three interrelated lines, viz. he laid the experimental and mathematical foundations of natural science, demonstrated a convincing example of the inculcation of new science and scientific thought, and entered into controversy with the Roman Inquisition in defense of the anti-Aristotelian picture of the world and cognitive scientific methods.

The first two spheres of Galileo's activity played an important role in the development of science and enlightenment methods. They further promoted culture and continue to facilitate the cognition of nature and shape scientific world outlook of the general public through publications on the history and philosophy of science, popular scientific books, etc. Galileo's anti-Jesuit struggle gave rise to a wave of passion, the impact of which is still being felt in our difficult days.

Speaking of the role of Galileo in 17th century science, S I Vavilov noted that "Galileo was amazingly endowed with a gift of... inculcating scientific truth" [1, p. 584]. Galileo made a great contribution to the development of science, but his enlightening activity is equally important for the formation of scientific culture in pursuit of exhaustive understanding natural phenomena.

Knowledge comes and goes, while the necessity and ability to transfer it to future and present generations of researchers, philosophers, and the public at large are perpetual. The scientific culture of a society lives and develops as long as it needs science and there are people capable of realizing such a necessity; hence, the vital importance of bringing up new Galileos with their enthusiasm, talent, and energy.

2. From scholasticism to a new thinking

Galileo Galilei was born on 15 February 1564 in Pisa. His father, a composer and music theorist, managed to give him a humanities education. However, his creativity stems not from studying music and pictorial art but from Florentine technologies that enabled people of that time to conquer and subdue nature. Interest in these matters brought him to the realm of mechanics and applied mathematics dominated by considerations of practical rationality and elegant simplicity.

However, Galileo's father wanted his son to study medicine and sent him to the University of Pisa in 1691, where Galileo made himself thoroughly familiar with Platonic and Aristotelian philosophies and with Euclidean mathematics and Archimedes mechanics; later, Galilei called Archimedes his teacher. While studying mechanics, Galileo came to an understanding that its problems should be addressed and solved based only on real experiments rather than abstract principles.

V Viviani, a pupil of Galilei, recollected how his teacher observed, "with his natural curiosity and wit," a swinging chandelier inside the Pisa Cathedral using his own pulse rate and musical rhythm to measure time intervals. These observations brought him to a cautious conclusion (1583) in support of his early hypotheses for isochronic pendulum motion [9, Vol. II, p. 443].

Galileo's interest in mechanics made him ultimately give up medicine and leave the university shortly before graduation. Having returned to Florence, he thoroughly studied mathematics and successfully solved the problem of hydrostatic equilibrium and balance (1586), and wrote a treatise on the center of gravity in solids and other topics. At this point, he arrived at the conclusion that Aristotle's interpretation of motion needed to be revised.

In years to come (1611), Galilei would write as follows about his great predecessor, whom he treated with the greatest respect: "... I often disagree with Aristotle over many issues not on a whim and not because I did not read or did not understand him but by virtue of conclusive evidence. Aristotle himself taught me to satisfy my mind with convincing arguments rather than just rely on the teacher's authority..." [9, Vol. II, p. 43].

Doubting in Aristotle's physics, Galilei nevertheless preserved thus far his cosmology and cognitive methodology, as well as belief in the possibility of gaining knowledge about the properties of things. At the same time, Galilei came to recognize the crucial role of experiment in discovering the laws of nature and began to acquire sufficiently strong skills in analyzing observations, as well as in designing and carrying out experiments, with a special emphasis on mental experiments.

Being the author of widely acclaimed scientific works, Galileo tried to take the position of a university teacher in Bologna but failed. In 1589, he returned to the University of Pisa as professor of mathematics, where his pedagogical and educational activity started. The 25-year-old professor read lectures on astronomy and mathematics; he also gave private lessons to earn extra income.

Here, Galileo studied the lecture notes of professors from universities in Pisa and Rome on logic, philosophy, and natural philosophy. At the same time, he wrote comments on Ptolemy's *Almagest* in the hope of publishing it. Ultimately, he came to the conclusion that Aristotle's views of motion were wrong and wrote a treatise *On Motion* (1590). In the meantime, he began to develop an interest in the Copernican doctrine.

Till that time, the conjectures of Copernicus were just common sense arguments. Actual observations were needed to confirm that all events, earthly and celestial, obey the same natural laws. However, Galilei could not seriously engage in this matter in the face of the enmity of many professors, provoked by his criticism of authoritative scholars, the independence of judgment, etc. Two years later, Galilei was forced to leave the University of Pisa.

In 1592, the 28-year-old Galilei became professor of mathematics at the University of Padua. His opening lecture made a vivid impression on the audience by the adduced facts and its logical content. As Galilei was an excellent speaker and teacher, his lectures attracted everybody's attention and were admired for the force of arguments, virtuosity, and eloquence that enabled him to win debates with opponents.

3. Learning nature's harmony through experience and computation

Galilei himself considered his 18 years spent at the University of Padua to be the most productive and happy period of creative work. He introduced students to such topics as the sphere and Euclid, Ptolemy's *Almagest*, Euclid and Aristotle's mechanics, and the theory of planetary motion. In the meantime, he accumulated scientific materials that present-day historians of science collectively call 'Padua mechanics' [7, p. 157].

After Galileo's father decease, as the eldest son Galileo had to provide financial support for the rest of the parent family and to establish acceptable conditions for his own family as well. Lack of money haunted him during all his life. Soon he began suffering rheumatic pains followed by new health problems. His love and care for his beloved daughter Celeste (while she was alive) remained the greatest source of strength through his most difficult years.

Of the disciplines taught at the lectures, Galileo laid emphasis on geometry and astronomy. At first, they did not contain new ideas or concepts suggesting any departure from Aristotle's physics. It may be conjectured that he argued in favor of the Copernican doctrine at his private lessons but not in the classroom, where he kept silence owing to the absence of conclusive evidences gathered by him.

Meanwhile, Galilei learnt from his friend Sagredo that Giordano Bruno was found guilty of heresy and burned at the stake on 17 February 1600. Coincidentally, Cardinal R Bellarmine, the chief prosecutor at Bruno's trial, will decide the fate of Galilei himself 15 years later. But Galileo still had a long path of creative research and doubts ahead of him, not thinking about his bleak future.

Retaining keen interest in technology and building, he set up mechanical and optical workshops. He produced here devices and instruments needed for conducting his own studies. Galileo constructed a thermometer (1592) and a water-lifting machine (1594), and invented a proportional compass for engineering (1606), widely being tapped during subsequent years.

When solving technical problems, Galileo increasingly often dealt with mechanics. During the first year at the University of Padua, he published *Mechanics* concerned with the statics of simple machines executing displacements with the aid of the lever and the inclined plane. This work was translated into French and English during his lifetime (in 1634 and 1636), bringing fame to him.

Taken together — acquisition of technical skills, familiarity and experience with university science, awakening interest in dynamics and then in mathematics — ultimately resulted in practical mechanics showing its theoretical side to him and becoming a source of study objects and a "school of ingenious experiment" [5, p. 217].

In a letter dated 1604, Galileo informed his friend Paolo Sarpi that he was about to address the law of free fall of bodies, now known to schoolchildren. In his note on accelerated motion, he came from the initial erroneous assumption that the velocity of an object is proportional to the distance travelled to the correct conclusion that the distance is actually proportional to the square of the time elapsed, namely $s \sim t^2$.

When considering his own discoveries in the context of the Copernican doctrine, Galilei stressed its importance for mechanics. He wrote to Johannes Kepler: "I have shared the views of Copernicus for many years now, and it has helped me to find a plausible explanation for a body of observed natural phenomena... " [10, p. 91]. But, no matter how deep Galileo plunged himself into the 'technology–mechanics–astronomy' problem at that time, he could not have cared less about astronomy research in the near future.

One of the major achievements in the origin of astronomy was the invention of the telescope. Galilei fabricated his own device in 1609: "... I made a lead pipe, to the ends of which I fitted two optical glasses, each having one side flat and the other either spherically convex or concave; then, bringing the eye to the concave glass, I saw objects that were quite large and much closer..." [9, Vol. I, pp. 21–22].

The scientist built a dozen telescopes, the last one magnifying some 32 times. He was well aware of their inestimable benefit for all transactions and undertakings, maritime and military. "Setting aside all earthly objects, I confined myself to studying celestial ones." During two months, he discovered mountains on the Moon, satellites of Jupiter, spots on the Sun, and phases of Venus; also, it turned out that the Milky Way comprises a multitude of stars, and Galilei discovered the libration of the Moon, and obtained evidence of a nonstationary 'stellar world.'

Galileo wrote in *The Starry Messenger* of 1 March 1610: "It can be stated with confidence that the Moon's surface is mountainous and not a perfect sphere... on the contrary, it is rough, covered with highlands and low-lying areas shaped exactly like those on the Earth..." [9, Vol. I, pp. 23–24].

Even more remarkable is his explanation of the essence of Galaxy: "Indeed, the Galaxia is nothing but a collection of numerous stars assembled into groups. Wherever you direct the telescope, you can see a huge number of stars, many of which are rather large and conspicuous; the multitude of smaller ones is beyond exploration" [9, Vol. I, p. 37].

The discoveries described by Galileo in *The Starry Messenger* greatly impressed his contemporaries and provoked much debate among European scholars. Galileo became exceptionally famous. The fame came to him together with honors. He was awarded the prestigious title of 'First and Extraordinary Mathematician and Philosopher' by the University of Florence, whither he moved with great pleasure and expectations.

In the same 1610, Kepler in Prague published a treatise, *Astronomia Nova*, where he formulated the first two laws of planetary motion (the third law came in 1619). Kepler built his telescope in 1611 and described it in *Dioptrice*. For a short while, the two scientists sharing an interest in optics and astronomy but having different views of the same entities maintained correspondence.

However, new discoveries do not immediately take hold of mass consciousness. It also depends on the epoch. For "at the dawn of classical science it was necessary to transform not only the people's... worldview but also their way of thinking, so that the new science could enter their mind. Therefore, Galileo's propagandistic nature was historically justified" [9, Vol. II, p. 488].

Galileo discussed issues of concern with friends and those interested in the latest scientific news. In frank conversations with like-minded colleagues from Padua, Venice, Florence, and Rome, he talked about observations confirming, in his opinion, the Copernicus doctrine. In 1611, Galileo was elected for his achievements to the Lincean Academy (a scientific society in Rome, one of the oldest in Europe).

After an undeniable victory in a dispute on the nature of cold in 1612, Galileo published the *Discourse on Floating Bodies*, intended for a nonspecialist audience: ("I wrote in the colloquial dialect, because I wanted everyone to be able to read this book"). It proclaimed and proved a number of scientific truths and provided substantiation of his research methods.

However, none of the clerics accepting Galileo's discoveries and glorifying him as a pioneer in science ever recognized the objective essence of his findings, and in the first place the truth of the heliocentric system, on the grounds that science cannot be a source of objective knowledge if it disregards canonical ecclesiastical dogmas.

Therefore, as soon as Galileo entered the sacred territory, on which there was no place for the Copernicus doctrine and other scientific ideas that he propagated and defended, he immediately gained enemies among believers, and especially churchmen. Information against Galileo and his answers to these attacks were thoroughly scrutinized by the Catholic Church, and the danger of his views soon became apparent to the clergy.

Galileo was determined to uphold his views in the face of the new challenge and undertook a trip to Rome armed with the letters of recommendation testifying to his loyalty to the Holy Scripture. He met with a majority of his benefactors, but the sole result of his efforts was that church officials decided to let him alone. However, the theologian censors condemned Copernican theory in February 1616. The decree of the Sacred Congregation dated 5 March, 1616 banned Copernicus's doctrine expounded in his book *De Revolutionibus Orbium Coelestium* and publications in support of the heliocentric system.

The key figure in these events was again Cardinal R Bellarmine, who would not recognize the right of researchers to interpret the Holy Scriptures. Before Galilei left Rome, Bellarmine handed him a certificate by which Galilei was notified of the decree and informed that, as a consequence of it, "the Copernican doctrine according to which the Earth revolves around the motionless Sun as the center of the Universe... cannot be defended or held, as it contradicts the Holy Scriptures" [4, p. 125].

It turned into tragedy for the scientist convinced of the progressiveness of the heliocentric system and its recognition by other intellectuals. Galileo had to abstain from discussing and defending the new teaching for the next eight years. But it did not make him give up scientific work, which continued in a subtle and inconspicuous way.

In 1623, Galileo published a new book, *The Assayer*, where he emphasized the importance of authority-independent quantitative studies of nature and regarded qualitative properties as secondary, reducing them to the size, shape, amount, motion, and configuration of uniform discrete components of matter lacking qualities. However, he still experienced a scarcity of evidence from observations, experiments, and calculations.

Galileo considered mathematics to be an arbitrator validating the truth of the results obtained, emphasizing that the book of the Universe "always greeting our eyes can be understood only by those who will learn to comprehend its language and interpret the signs in which it is written. It is written in the mathematical language, and its signs are triangles, circles, and other geometric figures..." [11, p. 41].

Galileo related mathematical implications as regards "indivisibles" (for "continuum is composed of absolutely indivisible atoms") to the structure of matter. Consideration of bodies as composed of indivisibles permitted "understanding the phenomena of dilution and thickening of bodies without assuming the existence of voids to explain the former or the interpenetration of bodies to account for the latter" [9, Vol. II, p. 154]. Thus, Galileo moved from mathematical to physical atomism.

The Assayer was intended to educate Italian and European elites. Challenging the established views in philosophy, demanding an independent language for physics, upholding the right of free scientific work and public discussion made this book a manifesto of progressive philosophy of cognition and science free from submission to academic authorities.

By that time, Galileo had already had a bitter experience in seeing how his ideas were taken by others. He wrote in *The Assayer*: "As soon as I happened to present my observations to the public, either for pleasure or benefit, many wished to belittle, defame, or steal that little bit of gratitude that my intentions, if not my work, deserve" [5, p. 15].

Evidence of continuing scientific work in the period of enforced silence was the publication of *A letter to Francesco Ingoli* (1624), in which Galileo recalled his unwavering commitment to the development of new science by stating: "We remain obliged to higher sciences, which are the only ones capable of dispelling the darkness in which our mind is immersed..." [9, Vol. I, p. 60].

This letter contained his famous assertion about the relativity of concepts and measure definitions that medieval science had considered absolute. In the same treatise, Galileo developed the doctrine of relativity of motion deduced from thought experiments done in a ship's hull at rest on a water surface moving uniformly in a straight line. Today, these experiments are universally known and included in physics textbooks.

Galileo tried to prove the truth of Copernicus's heliocentric system from the standpoint of mechanics and astronomy. A summary of his arguments was presented in the same letter to Ingoli, where he dwelt on cosmological issues, in addition to relativity. Galileo had to search for ways to substantiate the concept of heliocentrism that would allow him to avoid the charge of heresy.

Galileo, educated and brought up as a humanities-minded person, endowed with a gift of observation and scientific analysis of natural phenomena, capable of understanding due to this the integrity of physical phenomena, checked up in his work nature's harmony with algebra, and thereby laid the foundation of the rational perception of the world, without which it is impossible to apprehend it and harness its resources.

4. Witness of absolute truth in the face of the world

It should be noted that at the beginning of the Florentine period Galileo had high hopes for the freedom of public statements and was greatly disappointed when they proved delusive. Moreover, the initially benevolent attitude of the authorities changed, and he began to notice signs of upcoming persecution for free thinking about the structure of the Universe.

In the years when Galileo was deprived of the opportunity to continue teaching at the university and during the subsequent period when propagating the Copernican doctrine was banned, he was focused on the search for decisive arguments in favor of the heliocentric system. The new studies published by Galileo gave evidence of the undoubted successes of his efforts and of the marked progress in the development of new science, its methodology, and philosophy.

The scientist summarized the known arguments, involving those found by himself, in the treatise *Dialogue Concerning the Two Chief World Systems* (1632). In this work, he refined the form and content of the available material substantiated by the experimental testing and mathematical treatment but discarded detailed calculations to facilitate its logical presentation and understanding by the reader with due regard for the emotions and opinions of the participants in the dialogue.

The manner of discussion in *Dialogue* betrays Galileo as an unrestrained, self-willed enlightener striving to subjugate opponents. At the same time, "before responding to the arguments of an opponent, he simplified and discounted them by clear and self-explanatory evidence that not only demolished them but also discredited and stultified the critic" [12, p. 66].

In the end, the problem raised by the differently minded person was discussed in the form of a conversation about natural phenomena with a humanist slant. The concepts of the structure of the Universe were presented in the form of a dialogue intended to arrive at scientific truth. Yet, for all the precautions taken by Galileo, *Dialogue* was subjected to strict censorship that demanded extensive cuts and revision of the text.

Dialogue is actually a popular guide to the problem of motion and related issues. At the same time, it is "a pedagogical manual designed to refute Aristotle's formalism and persuade honest people to accept the new worldview ensuing from the Copernican doctrine" [13, p. 77]. Astronomical and mechanical evidence in favor of this doctrine listed in *Dialogue* disprove the Ptolemaic geocentric views in a readily understandable format.

The text is designed as a series of discussions among three Venetians: Salviati (probably Galileo's friend and disciple passing on the thoughts and judgments of the author), Sagredo (a quite enlightened interlocutor having to choose between the philosophies of Aristotle and Galileo), and Simplicio commenting most likely on Aristotle's views. The first two characters had died by the time *Dialogue* was published.

The fourth participant in the dialogue is Galileo himself, disguised under the name Academician, who subtly directs the discussion of the world of ideas. On the first day, the interlocutors discuss the uniform motion of bodies, the second day is devoted to the daily rotation of the Earth, and the third day covers the annual motion of the Earth and other planets around the Sun (also discussed are experiments on magnetism and the Earth as a natural W Gilbert magnet), and the most important issue on last day 4 is the theory of the ebbs and flows.

The truth of heliocentrism is confirmed by the relativity principle of motion, the laws of inertia and free fall of bodies (later developed by Newton and then by Einstein [3]), the motion of bodies over an inclined plane and of those thrown at an angle to the horizon, the laws of addition of velocities and isochronic oscillations of a pendulum, the experiments in the ship's hull as an illustration of the relativity of motion and rest.

The simplicity of the experiments, conditions of their running, and appeal to common sense with its paradoxes and artistic images helped to excite reader interest and desire to understand the actual for that time problems of motion and to comprehend their essence and the force of arguments in their support. But the forms of substantiation of truth in *Dialogue* extended further than that.

Practical logic and imaginative comparison were not enough to motivate readers to abandon geocentric concepts and believe Copernicus. Galileo artfully appealed to their psychology, relying on the dialogic mode of thinking [6]. *Dialogue* is designed so that reasoning obeys the conditions which gave rise to it. Salviati says: "These argumentations depend on those things that start up in the fancy not of one person, but of three, which we are. And, moreover, we discourse for our pleasure and are not obliged to that strictness of one who *ex professo* treateth methodically of an argument, with an intent to publish the same. I will not consent to our Poem (*Dialogue* — *R. Shch.*) being so confined to that unity, as not to leave us fields open for episodes..." [9, Vol. 1, p. 261]. [Inglished from the Original Itali'n Copy, by Thomas Salusbury.]

The dialogue develops by analyzing the Ptolemaic worldview along with the quite different Copernican teaching. At first, two mutually exclusive concepts exist simultaneously in our mind. But in the course of time, the superiority of heliocentrism over geocentrism becomes increasingly apparent, and the radically new concept gradually predominates. The process proceeds smoothly, without violence against the person.

A dialogue between interlocutors apropos of the newest comprehension of the world is composed by Galilei so skillfully that logical and geometrical constructions, imaginative and literary reminiscences, descriptions, polemic statements, and emotional confessions of the author taken together gradually liberate the readers from the previously adopted views and mode of thinking about nature and themselves.

Dialogue destroys outdated notions of the nature of Earth and space and offers instead a new knowledge on which to form, where possible, a scientifically based outlook. The author puts the following words in the mouth of Salviati: "humane wisdom understandeth some propositions so perfectly, and is as absolutely certain thereof, as Nature herself .." [9, Vol. I, p. 201].

According to Einstein, "Galileo speaking in defense of Copernicus and fighting for his doctrine was guided not only by the desire to simplify the idea of the motion of celestial bodies. His goal was an intense and impartial search for a deeper and more consistent understanding of physical and astronomical facts in order to replace the rotten and vicious system of ideas" [14, p. 339].

Thus, Galileo convincingly substantiated the truth of Copernican doctrine at the logical, philosophical, rhetorical, and psychological levels, which ensured him widespread popularity among European intellectuals [8, p. 171]. Nevertheless, his efforts were insufficient to instil a scientific view of the world in the general public, nor could it become an integral element of the general culture.

Major social changes in the entire European society were needed to make heliocentric views essential for ordinary people and widely accepted in Europe. Galileo had to shift the strength of his arguments from the sphere of visible evidence ("I see with my own eyes") to the realm of unobviousness ("I see with my mental eyes"). Only in this way could the ideas of Copernicus be naturally integrated into European culture [15, p. 84].

However, new problems emerge and old ones sink into oblivion as time goes by. In the 19th century, F Arago ironically commented on *Dialogue* in the following words: "the simplest ideas are explained verbosely so that in our time the book seems boring. It does contain rational thoughts, but they are lost in a bunch of worthless courtesies with which the speakers exchange" [16, p. 76].

At present, *Dialogue* is thoroughly investigated, barring minor details [8, p. 62]. In our time, its worth lies in the didactically and literarily masterful presentation of a popular and rather educational guidance, an example of how it can help in the understanding of radically new ideas and the search for promising forms and methods of teaching and science popularization.

5. Public defense of new science and mentality

Trying to reconcile his scientific beliefs with the ideological and political doctrines of his epoch, Galileo better than anyone else understood the inevitability of conflict with the Catholic Church and its Inquisition. He most likely guessed that he was close to the tragic end despite the precautions he took to remain loyal in the eyes of society and church authorities.

The popularity of *The Starry Messenger*, *The Assayer*, *A Letter to Francesco Ingoli*, correspondence, and especially *Dialogue* attracted the unwanted attention of the Inquisition. Moreover, not only professors and theologists but also ordinary believers on Divine World, did not share Galileo's views lent an attentive ear to his scientific findings, critically apprehended them, felt offended by his statements and had for a long time written letters of information against him.

But the main danger came from the personal ambitions of Pope Urban VIII. Frustrated over the political crisis and diminishing spiritual authority of the Church, the pope looked for a means to strengthen his theological positions. He regarded *Dialogue* as an attempt to undermine the authority of himself and the Church at large. He could not allow the Copernican theory to claim to have an objective sense, even though he had shown great favor to Galileo in the past.

A series of indictments against Galileo were prepared in connection with the publication of *Dialogue* in 1632 and earlier developments of 1616. He was summoned to Rome and arrived there in 1633 to stand trial, which lasted from April to June. Galileo was interrogated and the sentence of the Inquisition was issued on 22 June (in the monastery of Santa Maria sopra Minerva), by which he was found "vehemently suspect of heresy" and ordered to renounce his belief. *Dialogue* was banned and its author sentenced to imprisonment and repentance.

As a result of all these dramatic events for Galileo, scientist and man, he was forced to declare publicly the abjuration of his 'false' opinion: "...with sincere heart and unfeigned faith I abjure, curse, and detest the aforesaid errors and heresies, and generally every other error and sect whatsoever contrary to the said Holy Church" [4, p. 217].

Galileo's abjuration brought satisfaction to ill-disposed believers but was a letdown for his adherers. After Galileo's condemnation, R Descartes wrote in a letter to Mersenne: "I was so astonished at this that I almost decided to burn all my papers or at least to let no one see them.... If the movement of the Earth is false, all the foundations of my philosophy are false, too..." [17, p. 481].

Galileo, unlike Giordano Bruno, was spared execution by virtue of the favor given to him by the pope and his inner circle, who sought to strengthen their political and religious positions by saving the life of the scientist recognized as a pillar of Catholic culture. According to a popular legend dating from that time, Galileo, after recanting his theory, allegedly muttered the rebellious phrase "*Eppur si muove* (And yet it moves)."

Anyway, the process served to popularize Galileo as a scientist and a public figure. Sentenced to life imprisonment, he was soon allowed to move to Sienna near Florence, and six months later returned to live in his villa in Arcetri, where he remained under house arrest till death. For the rest of his days, Galileo signed his letters as follows: "From my prison in Arcetri."

Only at the end of the 20th century did Pope John Paul II call the condemnation of Galileo by the Inquisition tragic mutual incomprehension; the case of Galileo was closed, and the scientist was rehabilitated. The 400th anniversary of the invention of the telescope and the first telescopic observations by Galileo Galilei were celebrated in 2009 as World Astronomy Day.

6. Creation of a new science of a very old subject

Within two weeks after the dramatic trial, the 69-year-old Galileo came around and turned to mechanics. In 1638, he published in Holland *Discourses and Mathematical Demonstrations Relating to Two New Sciences*, which presented a more complicated kinematic picture of the world, involving accelerated motion in force fields.

In contrast to *Dialogue* directed against the Aristotelian concept of the static harmony of being, where "swords clatter and arguments, if not people, collide, fall, rise, and fall again," his *Discourses* "are imbued with calm reconciled wisdom ..." [4, p. 225] which came to Galileo with the experience of life and the 40-year scientific career that posed new challenges.

Discourses were not designed to educate the reader. They were intended for professionals and therefore contained an updated presentation of the issues proposed for discussion. Basically, these were problems of mechanical similarity, oscillations, acoustics, structural mechanics, mechanical movements, and optics. Galileo considered them taking into account the expertise of artisans, experiment, and calculations.

He demonstrated possession of the quantitative characteristics of speed and acceleration, understanding the forms of the laws of accelerating forces and inertia [18], and proved that the period of oscillations of a pendulum depends on the string length rather than its mass: "pendulum lengths are inversely proportional to the number squared of oscillations for a given period of time" [9, Vol. II, p. 190].

As usual, Galileo relied on real experiments and mental reasoning. For example, he verified the law of free fall of bodies by an inclined plane experiment. "A groove was cut along the narrow side of a ruler or rather a wooden board ... and a hard, smooth, and very round bronze ball was rolled down the groove."

Galileo used a bucket of water, a glass, and scales to measure time, and changed the angle of inclination of the board and the path length of the ball. Repeating "the same experiment many times to accurately determine the time ... we always found that the ratio of the paths covered was equal to the squares of the elapsed time, regardless of the tilt of the plane, i.e., the groove down which the ball rolled" [9, Vol. II, p. 253].

Galileo argued that the speed of a body is its intrinsic property, "while the causes of acceleration or deceleration are external variables; it can be seen only on a horizontal plane, because motion down an inclined plane leads to acceleration of a body, and the upward motion to slowdown. This suggests that the motion over the horizontal plane is eternal..." [9, Vol. II, p. 282].

Galileo was the first scholar of his time to realize the importance of the unity of science and production. In *Discourses*, he emphasized that technical practice provides experimental material for future theoretical findings. He insisted on the relevance of consideration of technical problems in the physicomathematical context. In such a case, the employment of experiment in combination with computational mathematics acquires special importance.

Also discussed in *Discourses* are problems of geometric and physical optics. In particular, Galileo describes attempts to determine the speed of light by two observers with lanterns. The experiment failed, but the scientist concluded correctly that the speed of light is finite. Galileo also conducted experiments with a prism, observed the diffraction of light, and showed interest in phosphorescence.

Galileo planned to write later a paper on optics. S I Vavilov conjectured that "it would have been in Galileo's favorite form of a dialogue or discourse logically irreproachable, with an artistic slant and comprehensive content based on experiment, observation, and scientific philosophy" [2, p. 615]. But this plan was not realized, and the preliminary work done by Galileo turned out to be in vain.

Thus, Galileo's last work was a serious study summarizing his life-long experience as a researcher in a field that a century later acquired the status of an experimental and mathematical discipline, namely, mechanics and physics. Certainly, *Discourses* will in due course attract more attention of the historians of science and philosophers.

However, based on the studies from the sides of history, philosophy and psychology they will hardly be able to decide whether he built new physics from geometric theory to experiment, created mechanics based on his favorite empirical approach, or mostly relied on the argumentation theory.

7. Summing up the life of the Italian genius

While in prison, Galileo did not interrupt close contacts with other scholars, as is evidenced by correspondence with J Borelli, B Cavalieri, B Viviani , B Castelli, M Mersenne, and E Torricelli. His letters to them were intended to broaden their outlook and support those ideas and concepts which he deemed promising for the further development of new science, philosophy, and practice.

Publication of *Discourses* coincided with Galileo's blindness. "This universe, which I with my astonishing observations and clear demonstrations had enlarged a hundred-, nay, a thousand-fold beyond the limits commonly seen by wise men of all centuries past, is now for me so diminished and reduced, it has shrunk to the meager confines of my body" [12, p. 466].

Galileo died on 8 January 1642, a month before his 78th birthday, and was buried in the Basilica of Santa Croce. Viviani, Torricelli, and Galileo's son Vincenzio were at his bedside when he breathed his last. The first collection of his works was published in 1656, but *Dialogue* was not yet be included. These writings reflected Galileo's scientific ideas and his contributions to science and culture.

As L Ol'shki opportunely observed: "Galileo was the last of those universal dominant personalities who derived the eternal values from the overflowing mass of achievements of ancient and new national and European culture, united them into an organic whole, revealed their true sense and universal significance, determined the goal and right direction of their further development" [19, p. 313].

Like most of his contemporaries, Galileo was a humanist, naturalist, mathematician, and philosopher. Learning to apprehend the natural phenomena by means of logical reasoning, experiment, and calculations, he believed in their independent existence. The scientist emphasized that not only nature but also the potential for its learning are infinite, that matter is uniform and indestructible, and that the world is rational and subject to mechanical causality.

According to Galileo, finding out the causes of natural phenomena is the principle goal of science. To prove the truth of scientific beliefs means to proceed "from their primary and indisputable foundations" [9, Vol. II, p. 120]. Hypotheses themselves should be tested by experiments, either real (pendulum or inclined plane) or preferably mental. Such experiments lead to important conclusions if properly designed.

According to Salviati, "The Academician has always been an experimentalist no less diligent than inquisitive" [9, Vol. II, p. 382] who considers experiments as a search for the explanation of the mechanism underlying a given phenomena for himself and others. Any explanation is doomed to be tentative because there is no object free of external influences; therefore, the experimentalist "should not be surprised if he fails..." [5, p. 234].

Indeed, the scientist tried to 'clean up' phenomena from outside influences in real experiments, nor did he forget to do the same in his mental experiments. He gave preference to the latter over the former, first because real experiments were difficult to conduct in his time, second because their results did not convince adherents of Aristotle's physics, who mostly relied on logical reasoning underlying mental experiments.

V S Bibler attributes the force of arguments putted by Galileo into these experiments to the fact that "*Dialogue* does not contain a single mental experiment on an idealized object other than an experiment on the inner speech unlocking the hidden potential for the conversion of Aristotelian logic into Copernicus' logic" [6, p. 188].

As far as mathematics is concerned, it was for Galileo the language of science and a tool for insight into natural phenomena. He considered geometry to be the most reliable method and rarely resorted to arithmetic or algebra in mathematical calculations, which led to a shortage of research instruments and imprecise metaphysical and physical inferences [20, p. 312].

This and many other factors account for a number of erroneous conclusions about the nature of phenomena, made by Galileo. For example, his telescope was not strong enough to enable him to see the rings of Saturn, Galileo ignored Kepler's law of elliptical planetary motion, the movement of his ship was along the great circular arc of the Earth's surface rather than strictly translational, his bodies fell vertically and did not deflect to the east or in a somewhat southern direction, etc.

The outstanding optical physicist and historian of science S I Vavilov wrote that the "physical and astronomical arguments of Galileo in favor of the Earth's motion are wrong, not new, or insubstantial; Kepler's laws escaped his attention or were not understood, the Galilean tidal theory is erroneous, and his views of comets seem archaic" [2, p. 584].

But all this became apparent later with the development of science and the advent of facts and evidence unknown to

Galileo. A man of genius makes no mistakes though; rather, they become gateways to new discoveries. Contemporaries (although few and lost among a multitude of laypeople) recognized Galileo's contribution to the substantiation of heliocentrism; his achievements in astronomy and mechanics were actively popularized by M Mersenne.

In a lecture given at the Galileo Symposium (Italy) in 1964, R Feynman emphasized the value of Galileo's ideas for science of the 20th century: "Suppose Galileo were here and we were to... tell him about the questions of evidence, those methods of judging things which he developed, we would point out that we are still in exactly the same tradition, we follow it exactly — even to the details of making numerical measurements and using those as one of the better tools, in physics at least" [21, p. 143].

In our time, I Yu Kobzarev, speaking on the importance of Galileo's works for the formation and upbringing of I Newton as a researcher, most convincingly suggests that "the books of Galileo were for young Newton the same as the Course of Theoretical Physics by Landau and Lifshitz or Rosenfeld's tables are for modern physicists" [22, p. 20].

Thus, in principle and on the whole, Galileo was a founder of experimental and mathematical natural sciences who made the first real steps in this direction. His creative activity greatly promoted formulation of the quantitative worldview that had been neither concrete nor unified before and could not pretend to be the true scientific world outlook.

Galileo's success in creating a new science was due to the use of research methods similar to modern ones. They included perception of a physical phenomenon (sensory experience), a working hypothesis (axiom), finding possible logical corollaries (mathematical elaboration), and, finally, experimental verification as the definitive criterion for a path of discovery [13, p. 81].

The historian of science, B G Kuznetsov, maintains that "a strong point of Galileo is mental experiments, kinematic and dynamic pictures, logical constructions, and the pathos of gaining mathematical insight into the visual world; the Galilean era is the dawn of mathematical analysis of the continuous motion of identical particles" [4, pp. 10, 11]. Galileo's work was followed by the mechanics of Descartes and Newton.

A Koyre, a French philosopher, noted that Galileo and his adherents had "to reform the structure of our mind, revise and reformulate the generally accepted concepts, propose a new vision of objective reality, formulate new definitions of learning and science, even replace the opinions seemingly correct from the common sense standpoint by radically different ones" [23, p. 131].

8. Conclusion: Galileo's message to posterity

Galileo Galilei was a representative of the humanist tradition in science and literature who did not hesitate to resort to imagination for the solution of scientific problems. But, unlike his contemporaries, Galileo distinguished between artwork and research, trying to make the latter truly independent.

His mode of thinking and research methods characterized him as a scientist capable of rational investigation into the very nature of things, adequate generalization of the available data, defense of scientific views against antiscientific ideas and unethical research practice.

"When we are told to deny our senses and subject them to the whim of others, people devoid of competence whatsoever are made judges over experts and are granted authority to treat them as they please. On the other hand, those having some information and understanding exercise judgment over novelties with great caution" [11, p. 113].

Galileo demonstrated by personal example the ideology of a physicist actively defending the values and principles of scientific work, who at the same time used his gifts and skills to match this ideology with that of the authorities and society of his time, i.e., adhered to the norms of conduct for scientific practice, mandatory in our time.

Galileo's principles of creative work and methods for their integration into social consciousness greatly influenced scientific and philosophical views of contemporary society. Of special value today is the method of dialogic communication that he employed to develop a scientific approach to the investigation of natural phenomena, comprehend natural laws, and convince public opinion in their objective character.

The contribution he made in *Dialogue* to overcoming obsolete notions and learning scientific truth is universally recognized. The creative activity of Galileo himself sets an example of the cultivation of the ability to perceive scientific knowledge to be followed by modern researchers.

Galileo stands in our imagination as a scholar and enlightener. The former, an ideal researcher, did his best to lay the foundations of mechanics, while the latter showed by his personal example how to promote new science and, thereby, to successfully form the foundations of scientific culture in the general public. The interest in Galileo's life and work continuing in this country from the 18th century up to now can be seen as more evidence of the contribution made by the Italian genius to science, philosophy, and education. Galileo perpetuated his name in the "History of the history of the Universe" [24, p. 540], but his drama remains relevant to this day as a matter of morals.

To conclude, Galileo's greatness arose from a combination of advanced research and active popularization of its results [25] in the hope to excite public interest in acquiring scientific knowledge and a mode of thinking, and thereby to support scientific activity as a guarantee of its own further progress.

References

1. Vavilov S I *Sov. Phys. Usp.* **7** 596 (1965); *Usp. Fiz. Nauk* **83** 583 (1964)
2. Krylov A N *Usp. Fiz. Nauk* **2** 143 (1921)
3. Fock V A *Sov. Phys. Usp.* **7** 592 (1965); *Usp. Fiz. Nauk* **83** 577 (1964)
4. Kuznetsov B G *Galilei* (Moscow: Nauka, 1964)
5. Akhutin A V *Istoriya Printsipov Fizicheskogo Eksperimenta* (*ot Antichnosti do XVII v.*) (The History of Principles of Physical Experiment (from Antiquity to the XVII Century)) (Moscow: Nauka, 1976)
6. Bibler V S *Ot Naukoucheniya — k Logike Kul'tury*: *Dva Filosofskikh Vvedeniya v Dvadtsat' Pervyi Vek* (From Epistemology to the Logic of Culture: Two Philosophical Introductions to the Twenty First Century) (Moscow: Politizdat, 1991)
7. Kirsanov V S *Nauchnaya Revolyutsiya XVII Veka* (Scientific Revolution of the XVII Century) (Moscow: Nauka, 1987)
8. Kosareva L M (Exec. Ed.) *Metodologicheskie Printsipy Sovremennykh Issledovanii Razvitiya Nauki* (*Galilei*) (Methodological Principles of Modern Research on the Development of Science (Galilei)) Ref. Sb. (Moscow: INION AN SSSR, 1989)
9. Galilei Galileo *Izbrannye Trudy* (Selected Works in 2 Volumes) (Comp. U I Frankfurt) (Moscow: Nauka, 1964)

10. Deborin A M (Ed.) *Galileo Galilei. 1564 – 1642* (Moscow – Leningrad: Izd. AN SSSR, 1943)
11. Galilei Galileo *Probirnykh Del Master* (The Assayer) (Exec. Ed. Ya A Smorodinsky, Comp., Transl. Yu A Danilov) (Moscow: Nauka, 1987)
12. Sobel D *Galileo's Daughter*: *A Historical Memoir of Science, Faith, and Love* (New York: Walker & Co., 1999); Translated from Russian: *Doch' Galileya*: *Istoricheskie Memuary o Nauke, Vere i Lyubvi* (Transl. O V Chumicheva) (St. Petersburg: AMFORA, 2006)
13. Gliozzi M "Storia della Fisica", in *Storia delle Scienze* Vol. 2 (Torino: Unione tipografico-editrice torinese, 1962); Translated from the Italian: *Istoriya Fiziki* (Transl. E L Burshtein) (Moscow: Mir, 1970)
14. Einstein A "Foreword", in Galilei G *Dialogue Concerning the Two Chief World Systems*: *Ptolemaic & Copernican* (Berkeley: Univ. of California Press, 1953); Translated into Russian: *Sobranie Nauchnykh Trudov* Vol. 4 (Moscow: Nauka, 1967)]
15. Kosareva L M "Kartiny Vselennoi v evropeiskoi kul'ture XVI – XVIII vv. (Na rubezhakh poznaniya Vselennoi)" ("The pictures of the Universe in European culture of XVI – XVIII centuries (At the turn of knowledge of the Universe)"), in *Istoriko-astronomicheskie Issledovaniya* Iss. 22 (Ed. A A Gurshtein) (Moscow: Nauka, 1990)
16. Arago F *Biografii Znamenitykh Astronomov, Fizikov i Geometrov* (Biographies of Famous Astronomers, Physicists and Geometers Vol. 1 (Transl. D Perevoshchikov) (Moscow – Izhevsk: RKhD, 2000)
17. Slyusarev G G "Dekart i optika XVII veka" ("Descartes and optics of the XVII century"), in Descartes R *Discourse on Method* (Ed. Transl. G G Slyusarev, A P Yushkevich) (Moscow: Izd. AN SSSR, 1953)
18. Tyulina I A, Chinenova V N "K ucheniyu Galileya o dvizhenii tyazhelykh tel" ("On the doctrine of Galileo on the motion of heavy bodies"), in *Issledovaniya po Istorii Fiziki i Mekhaniki — 1988* (Exec. Ed. A T Grigor'yan) (Moscow: Nauka, 1988)
19. Olschki L *Istoriya Nauchnoi Literatury na Novykh Yazykakh* (The History of Scientific Literature in the New Languages) Vol. 3 *Galilei i Ego Vremya* (Galilei and His Time) (Transl. F A Kogan-Berenshtein, P S Yushkevich, foreword by S V Vasil'ev) (Moscow – Leningrad: Gostekhizdat, 1933)
20. Pogrebysskii I B *Ot Lagranzha k Einshteinu* (From Lagrange to Einstein) (Moscow: Yanus, 1996)
21. Feynman R P *The Pleasure of Finding Things Out* (Cambridge, Mass.: Perseus Books, 1999); Translated into Russian: *Radost' Poznaniya* (Transl. T A Lomonosova) (Moscow: AST, 2013)
22. Kobzarev I Yu *N'yuton i Ego Vremya* (Newton and His Time) (New in Life, Science, Technology. Ser. "Physics", Iss. 5) (Moscow: Znanie, 1978)
23. Koyré A *Ocherki Filosofskoi Mysli* (Essays on the History of Philosophical Thought); Translated from French by Ya A Lyatker, Ed. and Foreword by A P Yushkevich) (Moscow: Progress, 1985)
24. Cherepashchuk A M *Phys. Usp.* **56** 509 (2013); *Usp. Fiz. Nauk* **183** 535 (2013)
25. Shcherbakov R N *Vestn. Ross. Akad. Nauk* **82** 1101 (2012)