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THE CONCEPT OF «MODERN PHYSICS» AND AN EXTENDED NEEDHAM QUESTION

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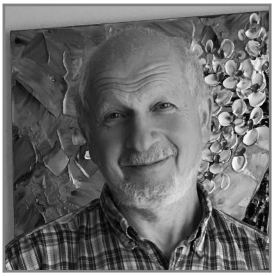

In discussions about the Scientific Revolution, a key expression is “modern science”. Its traditional understanding – mathematization and experimentation – is too weak: Euclid’s geometry and Archimedes’ physics were both perfectly mathematical and were based on objective experience. And it is too strong: in natural sciences beyond physics, math is quite limited. Joseph Needham in his Grand Question actually focused on modern physics originating with Galileo. To make this question really historical, it is narrowed down to physics and expanded in cultural time and space: *Which feature of modern physics, absent in Greco-Roman and Medieval sciences, prevented the next major advance after Archimedes, and prevented non-Europeans to join modern science for centuries after Galileo and up to the 20th century?* In modern physics, besides the tools of mathematics and experiment, no less important is the third tool, described by Einstein as «*the boldest speculation* [to] *bridge the gaps between the empirical data*». This tool implies *belief in the hidden fundamental laws of the universe and the right to invent fundamental concepts that are not directly observable, but can be tested experimentally along with the theory based on them*.
Such a belief, or the *postulate of modern science*, is the key distinction of modern physics. Among the great modern physicists there were eight theorists who successfully invented new fundamental concepts. And each of these inventions led to breakthrough advances of modern physics.

Keywords: modern physics, the Needham question, fundamental concept, the Scientific Revolution, the postulate of modern science

ПОНЯТИЕ «СОВРЕМЕННАЯ ФИЗИКА» И РАСШИРЕННЫЙ ВОПРОС НИДЭМА

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В дискуссиях о «научной революции» ключевое выражение – «современная наука». Его традиционное понимание – математизация и опора на опыт. Это понимание слишком широко, поскольку геометрия Евклида и физика Архимеда были математически совершенны и основывались на объективном опыте. И оно же слишком узко, поскольку в науке за пределами физики математика применяется весьма ограничено. Джозеф Нидэм в формулировке своего «Великого вопроса» под «современной наукой» фактически подразумевал современную физику, начатую Галилеем: «*Почему современная наука, с ее математизацией гипотез о природе и с ее ролью в создании передовой технологии, возникла лишь на Западе во времена Галилея, а не в Китае, где до XV в. знания о природе применялись к практическим нуждам намного эффективней, чем на Западе?*». По мнению близких сотрудников Нидэма, так сформулированный вопрос не может иметь исторического ответа, хоть эвристически он и сыграл огромную роль в мотивации самого Нидэма и его последователей в сравнительном изучении истории науки в разных культурах. Чтобы сделать вопрос Нидэма подлинно историческим, его следует переформулировать, ограничив физикой и расширив в культурном времени и пространстве: *Какая особенность современной физики, отличающая ее от науки Греко-Римской и средневековой, мешала следующему взлету физики после Архимеда и помешала ученым Востока подключиться к развитию науки после Галилея и вплоть до XX в.?* В современной физике, помимо математики и опыта, не менее важен третий инструмент, описанный Эйнштейном как «смелейшее изобретение понятий, связывающих разрозненные эмпирические данные». Этот инструмент подразумевает скрытые, но доступные познанию, фундаментальные законы Вселенной и право изобретать фундаментальные понятия, необходимые для описания явлений, выходящих за пределы обыденного опыта. Новые фундаментальные понятия современной науки непосредственно не наблюдаемы, но проверяемы экспериментально вместе с основанной на них теорией. По выражению Эйнштейна, такие понятия «являются свободными изобретениями человеческого духа, логически не выводимыми из опыта», а, по выражению Бора, они должны быть «достаточно безумны, чтобы иметь шанс оказаться правильными». И, действительно, все новые фундаментальные понятия современной физики казались нелогичными и даже абсурдными коллегам изобретателя при первом их появлении в языке науки и получали признание лишь после успеха теорий, основанных на них. Право на такой третий инструмент, или постулат современной науки, является ключевым отличием современной физики от до-Галилеевой. В истории современной физики лишь восьми теоретикам удалось успешно изобрести новые фундаментальные понятия. Это астро-математики Коперник и Кеплер, и физики Галилей, Ньютон, Максвелл, Планк, Эйнштейн и Бор. И каждое из их изобретений привело к прорывным достижениям науки.

Ключевые слова: современная физика, вопрос Нидэма, фундаментальное понятие, Научная революция, постулат современной науки

In world history, there were three major upsurges in scientific activity (and two declines), separated in space and time: the Greco-Roman period, the Islamic Golden Age, and the Modern European period.

Greek science emerged from the quest started by the Thales' question: What is the *Arche* (the first principle) of "everything that exists"? Various attempts to answer and develop this question led to the invention of the most convincing – axiomatic – system of theoretical knowledge in the form of Euclid's geometry and Archimedes' physics. Both the axiomatic ideal and these two theories remain valid to this day, although Greek science started to decline long before the fall of the Greco-Roman civilization.

A millennium after Archimedes, the scientists of the Islamic Golden Age started to assimilate and advance the scientific and technological achievements of Greco-Roman antiquity, India and China. Arabic became the language of the most advanced science, however, by the 13th century, science in the Islamic world went into decline.

The next major upsurge of scientific activity started in the mid-16th century as Copernicus' heliocentrism. The ensuing century and a half is traditionally associated with "the Scientific Revolution» that resulted in the emergence of «modern science." Both expressions are vague enough to allow prominent historians of science entitle their articles: "Was there a Scientific Revolution?" [Harrison, 2007; Heilbron, 2013]. Nevertheless, one feature of modern science stands out: unlike previous forms of science, the new one, for a few centuries up to the 20th, was adapted and advanced only within the European cultural realm. This feature was famously articulated by the prominent biochemist, historian of science, and renowned sinologist Joseph Needham [1969, p. 16, 190; 2004, p. 1]:

"***Why did modern science, the mathematization of hypotheses about Nature, with all its implications for advanced technology, take its meteoric rise only in the West at the time of Galileo?***", and why "***had*** [it] ***not developed in Chinese civilization***", which in the previous many centuries "***was much more efficient than Occidental*** [civilization] ***in gaining natural knowledge and in applying it to practical human needs***"?

Evidently, Needham [1959, p. 156] had in mind modern physics, as he wrote: "*the experimental-mathematical method, which appeared in almost perfect form in Galileo… led to all the developments of modern science and technology*".

Today, the word "science" is used much more broadly. Some historians of science use it "*inclusively to cover studies of art, literature and music… as well as facets of the physical and organic world*" [Ganeri 2013]. But Needham, in his question, was aiming at the origin of the natural sciences which played a key role in the 20th century and appeared to be universal and cosmopolitan.

The biochemist's view of Galileo as the originator of modern science is supported by the views of two top theoretical physicists from the 20th century. Albert Einstein and Richard Feynman were sufficiently interested in the origin of their profession to state that "*Galileo… is the father of modern physics – indeed, of modern science altogether*", and that "*the sciences have developed in a very good way directly and continuously from* [Galileo's] *original ideas, in the same spirit he developed*" [Einstein, 1960, p. 271; Feynman, 2005, p. 105].

A historian of science would add that Galileo had mastered Archimedean physics before Copernicus' discovery inspired and challenged him, but a proper question would be: *What was the actual innovation of Galileo that changed science so much and accelerated its progress a hundredfold?*

Hereafter in the article the expression "*modern science*" means first of all "*modern physics*", though in the 17^{th} century the accepted term was "*philosophy*" or "*natural philosophy*".

An Extended Needham Question

By the time Needham came to his question, the birth of modern science had already been termed "the Scientific Revolution" and explained in various ways: the needs of a capitalist economy, Protestant ideology, the "mathematization of nature", contacts between scholars and craftsmen, geopolitics, etc. [Cohen, 1994]. Inspired by Marxist historians of science B. Hessen and E. Zilsel, Needham himself looked for a "*sociological*" explanation that engaged "*the rise of the bourgeoisie*", though none of the suggested explanations satisfied him [Needham, 1971, p. vii–x; Needham, 2003; Gorelik 2018].

Needham, an eminent British biochemist, historian of science as a worldwide ecumenical enterprise, and greatest advocate of Chinese cultural heritage, was uniquely qualified to pose his "Eurocentric" question [Mougey, 2017; Mei, 2020]. He fell in love with China in the late 1930s, and this love affair helped him absorb a wealth of information about Chinese history [Needham, 1977]. However, his closest prominent colleagues in sinology were quite skeptical about his question. N. Sivin [1982] criticized it as a counterfactual question about a unique event, though he qualified it as a *heuristic* question. According to G. Lloyd [2020], "*we might conclude that the question as posed is incapable of resolution. The conclusion looms that what Joseph* [Needham] *continued to be preoccupied with was really an unanswerable question to which he failed to find a fully satisfactory solution*". At the same time, there is consensus that a "by-product" of Needham's preoccupation with the unanswerable question, his multi-volume "*Science and Civilisation in China*", is a monumental achievement. Unlike his colleagues in history of science, Needham was loyal both to the history of pre-modern non-European scientific endeavors and to modern science, which was his main occupation in the first decades of his professional life. Apparently, that is why he was so interested in the "genealogy" of the science that so profoundly changed the world in the 19^{th}–20^{th} centuries.

Anyway, the discussion about the Scientific Revolution continues without consensus in sight,[1] and the Needham question is passionately (and heuristically) debated both in the West and the East.[2] For example,

1 Cf. [Cohen, 2010; Huff, 2011; Heilbron, 2013].

2 See [Dun, 2000; Ducheyne, 2008; O'Brien, 2009; Raj, 2016; Jin, 2016; Mackerras, 2018; Hsia, Schäfer, 2019].

an Indian astrophysicist, basing on his experience in India and the US, came to the conclusion that "*it is necessary to have a proper* ['Western'] *psychological gestalt to practice science satisfactorily*" and tried to explain why it is "*difficult for non-Western scientists to acquire*" this "*gestalt*" [Choudhuri, 1985]. Two Chinese historians of science in their paper on the Needham question at the International Congress of History of Science and Technology of 2009, made an assessment: "*Compared with the huge system of universities and research institutes and the large number of researchers in contemporary China, the quantity of original scientific work accomplished is embarrassingly small*" [Liuxiang, Xiaoye, 2009].

To make the Needham question historically answerable, it should be narrowed down to physics and expanded in cultural space and time. Indeed, refuting Aristotelian physics, Galileo relied on the science of the "*superhuman*" and "*the most divine*" Archimedes [Galilei, 1590, p. 50, 115]. A reasonable historical question arises: Why did Greco-Roman scientists, for quite a few centuries after Archimedes, and then Arabic scientists, who had mastered Greek science long before the Europeans, fail to get ahead of Galileo, whose mathematics and experiments did not go beyond the capabilities of Archimedes? While the Galilean science was quite easily transplanted and took root in European countries, it failed to take hold in China, India and the Islamic world, whose innovations in science and technology had been assimilated in Europe by the 16th century.

The socio-cultural infrastructures of the great Eastern civilizations differed from each other no less than they differed from the European one. Thus, the real historical question is *not* why modern physics emerged in the West in the time of Galileo, but why it took so long since the time of Archimedes, and why Eastern civilizations were so delayed in joining modern physics.

Since these civilizations are so different, the comparative history of science founded by Needham is to be engaged, and, in the words of G. Lloyd [2020], "*a satisfactory account of what 'the' 'modern' scientific method consists in*" is to be produced. If modern physics differs qualitatively from previous forms of science, the Needham question should be reformulated:

What feature of modern physics, which was absent in the Greco-Roman and medieval sciences, for many centuries prevented the next major advance after Archimedes and prevented non-Europeans from joining modern physics for centuries after Galileo and up to the 20th century?

Such an extension of the Needham question expands its range in history to twenty-three centuries, and in geography to include Russia, where, despite the absence of native scientific tradition, modern science successfully took root as early as the 18th century.

There are quite a few likely sociocultural factors for science to flourish: institutional and human resources for education, general literacy rate, book printing, etc. But to deal with the origins of modern science, the first question is whether there is a key difference between modern physics and Greek science as ***convincing systems of objective knowledge***.

Modern Physics Is Fundamental and «Crazy Enough»

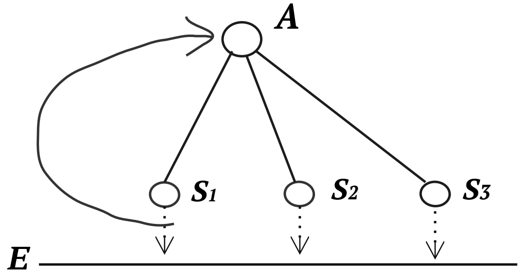
Needham [2004, p. 1] had a quite traditional definition of modern science as "*the combination of mathematized hypotheses about natural phenomena with relentless experimentation.*" Such a definition is too strong because the role of «mathematization» in natural sciences beyond physics is far more limited. And it is too weak because the greatest scientific achievements of ancient Greece – Euclid's geometry and Archimedes' physics – were perfectly mathematical and based on objective experience (Euclid's geometry, before Lobachevsky, could be considered a natural science, and indeed was so considered by Galileo). In short, the Greek ideal of knowledge as an axiomatic system is alive and well in modern physics. So what has changed?

According to the historian of medieval and early modern science, A.C. Crombie [1959, p. 122, emphasis added]:

"[T]*he Scientific Revolution came about rather by a* ***systematic change in intellectual outlook, in the type of question asked****, than by an increase in technical equipment. Why such a revolution in methods of thought should have taken place is obscure. It was not simply a continuation of the increasing attention to observation and to the experimental and mathematical methods that had been going on since the 13th century, because the change took on an altogether new speed and a quality that made it dominate European thinking.*"

Indeed, back in the 13th century, four centuries before Galileo, Roger Bacon stated: "*He who is ignorant of mathematics cannot know the other sciences and the things of this world*», and «*He, therefore, who wishes to rejoice without doubt in regard to the truths underlying phenomena must know how to devote himself to experiment*" [Clegg, 2003, p. 170, 175].

Measuring experiment and mathematics are indispensable to justify or reject a theory expressed in quantitative language. But in modern physics, a third tool, described by Einstein [1952, p. xxix] as "*the boldest speculation* [to] *bridge the gaps between the empirical data*", is no less important. It is inventive imagination, rather than mathematical or empirical inferences [Cohen, 2017]. Inventive imagination was the first step in the enterprise of modern physics, as depicted by Einstein [1993, p. 137] in the following diagram:



Here axioms ***A***, including the fundamental concepts for their formulation, are "*free inventions of the human spirit (**not logically derivable from what is empirically given**)*" [Einstein, 1949, p. 684, emphasis added]. Extra-logical inventive intuition takes off from the ground, or, rather, the runway, of experience ***E***. At the second step, some statements S_n are derived from ***A*** to be checked by landing in the ***E*** at the third step. If the landing is successful, the whole theory, including the invented fundamentals, is justified.

Creative intuition is a mysterious combination of a person's cultural resource, experience and genetics. According to Einstein [1930, p. 375]: "*The intuitive and constructive spiritual faculties must come into play wherever a body of scientific truth is concerned… Our moral leanings and tastes, our sense of beauty and religious instincts, are all tributary forces in helping the reasoning faculty towards its highest achievements*". (I would dare to edit it a little: "…*helping* [or hindering]…", but anyway "participating in the reasoning", and, thereby, deserving the attention of historians of science.)

Acknowledging his belief "*in intuition and inspiration*" Einstein [1931, p. 97] explained: "*Imagination is more important than knowledge. For knowledge is limited, whereas imagination embraces the entire world, stimulating progress, giving birth to evolution. It is, strictly speaking, a real factor in scientific research.*"

The words "intuition" and "imagination" are used by historians of science, when they have exhausted the documented scientific circumstances for the invention-discovery in consideration. These deeply personal notions are associated with thinking styles that can be very different for different creative people.

The inventor's imagination finds in his experience a reason to invent new concepts to formulate a new postulate, which – at the time of invention – seems absurd for non-inventors. In the words of Einstein [1993, p. 147, emphasis added], "***Concepts can never be derived logically from experience** and be above criticism… **Unless one sins against***

***logic,** one generally gets nowhere.*" Here he apparently means "against the logic of previous theory (or common sense)", since there is no other logic when an inventor's intuition takes off. Those extra-logical "*free inventions of the human spirit*" are really illogical for colleagues of the inventor.

Niels Bohr expressed the same understanding in discussing the idea of a new fundamental theory (suggested by W. Heisenberg and W. Pauli in 1958): "*We are all agreed that your theory is crazy. The question which divides us is whether it is **crazy enough** to have a chance of being correct*" [Dyson, 1958, p. 80, emphasis added].

Einstein's diagram describes only one cycle in the development of fundamental physics. In the course of its implementation and in the application of a new fundamental theory to new phenomena, new unexplainable experimental results or contradictions within the theory may appear. To comprehend such results and/or to resolve contradictions, new fundamental concepts will have to be invented and connected with the old fundamentals by certain correspondence. And then the next cycle of development begins according to Einstein's scenario.

Here is the key difference between Galileo's physics and the science of Euclid and Archimedes, as well as the principal similarity between Galileo's physics and the physics of Einstein and Bohr. In Euclid's geometry and Archimedes' physics, all the fundamentals stemmed (were taken) from common – visible-tangible – experience of land measurement and weight measurement (*point*, *straight line*, *lever*, *balance scale* and their axiomatic, i.e. self-evident, properties). On the other hand, in modern physics fundamentals are far from self-evident, they had to be "*crazy enough*", and their validations were results of the whole scientific enterprise joining theory and active experimentation well beyond common experience.

Of course, modern physics is an experimental science, and the main source of new knowledge is experimental discoveries, sometimes initiated by accidental observations (e.g. by Oersted, Roentgen, Becquerel, Rutherford…). However, without invented fundamental concepts – "invisible, illogical, and crazy enough to be correct" – physicists would not have the necessary words to describe and understand the puzzling results of experiments, to construct theories to explain them, and to conceive new experiments.

To invent a new fundamental concept, a modern physicist has to believe that: **the Universe is governed by profound exact laws that are hidden like the foundation of a building, but physicists have inalienable right to explore and comprehend these laws by inventing invisible, "illogical" (even absurd at the time of the invention) fundamental concepts to be empirically verified along with the theory, based on them.**

Such a belief could be called the *postulate of modern science* [Gorelik, 2017], or the *postulate of fundamental cognitive optimism*, combining boldest inventiveness with a humble need for objective empirical verification – the most fruitful attitude for modern science.

"The Magnificent Eight" Fundamental Inventors in the History of Modern Physics

The boldest idea of Copernicus, which, in his own words, "*seemed absurd*" [Copernicus, 1992, p. 5], was to take a careful look at the planetary motions from the "solar point of view". Kepler's boldest idea in dealing with extensive observational data was that the planetary motion is governed by a mathematically perfect law. For both of them, fundamental cognitive optimism supported laborious mathematical processing of astronomical data. Therefore, Copernicus and Kepler could be called *fundamental astro-mathematicians*.

Galileo became the first *modern physicist* by establishing the method of modern physics. He invented the first "illogical" physical concept – the vacuum (void) – despite the authority of Aristotle, who had "logically rejected" this notion. While scholastics discussed vacuum within the framework of logic and theology as "*the conception of an infinite separate space distinct from matter and associated in some manner with an omnipresent divine immensity*", "*Galileo fails even to discuss the subject*" [Grant, 2004, p. xii]. Indeed, Galileo was thinking about quite specific and experimentally observable earthly motion – free fall, and traditional theology had nothing to do with this thinking.

It was evident not only to Galileo that Aristotle's "law of fall" (that "swiftness of the mobile" is proportional to its "heaviness") was wrong, but the question was whether some "natural" (general, universal) law does exist. Being inspired by the physics of Archimedes and basing his own experiments on empirical realities, Galileo launched his "boldest speculations" about *motion in vacuum*, employing mathematical language and landing his speculations back in the empirical reality [Galilei, 1590, p. 34; Fredette, 2001, p. 165–181]. He never experienced vacuum through his senses and scientific instruments, but while comparing motions in air and water, he invented the concept of vacuum as a "*medium totally devoid of resistance*" [Galilei, 1914, p. 72] and finally came to the first universal laws – the law of free fall, the law of inertia, and the principle of relativity.

The next "invisible and illogical" fundamental concept – *universal gravity* – was invented by Newton who developed Galileo's physics into an integral system of classical mechanics. The new fundamental concept seemed *absurd* not only to such great scientists as C. Huygens and G. Leibniz, but also to Newton himself – even six years after he had published his *Principia*:

"That gravity should be innate, inherent, and essential to matter, so that one body may act upon another at a distance through a vacuum, without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity that I believe no man who has in philosophical matters a competent faculty of thinking can ever fall into it. Gravity must be caused by an agent acting constantly according to certain laws, but whether this agent be material or immaterial is a question I have left to the consideration of my readers" [Westfall, 1983, p. 472, 505]. (Newton's intuition was competent enough: in Einstein's theory of gravity, the "agent acting constantly according to certain laws" is the geometry of space-time, and I would leave to the readers to decide whether it is material or immaterial.)

The next fundamental concept – *electromagnetic field* – was invented two centuries later by Maxwell (who, most likely, would have recalled Faraday's "crazy" concept of "lines of force", which was the starting point for Maxwell). And then in a few decades Planck, Einstein and Bohr invented such fundamental concepts as *quanta of energy*, *invariance of the speed of light*, *quanta of light*, *curved space-time*, *quantum states*. The new theories based on these fundamental concepts, did not reject the old ones, but rather limited their applicability and established a workable correspondence between them, – another key feature of modern physics.

In total, as far as I can see, there were "the Magnificent Eight" fundamental inventors in the history of modern physics.

Describing Galileo's "*experimental-mathematical method*", Needham included, as a key element, the *"formulation of a hypothesis involving a mathematical relationship*", and mentioned just in a footnote, that "*Galileo did not hesitate to use* ***concepts of the unobserved and the unobservable*** *– such as a perfectly frictionless plane, or the motion of a body in empty infinite space*" [Needham, 1959, p. 156, emphasis added]. Indeed, at the turning points in the history of modern science, before formulating a new fundamental theory, its author invented specific "*concepts of the unobserved and the unobservable*".

It is a remarkable historical fact that new fundamental theories "rewarded" their inventors with consequences-achievements about which they did not think about when introducing new concepts. Galileo's idea to describe the fall of bodies in a vacuum appeared already in his 1590 manuscript, long before the decisive experiments and reflections that helped him come to the three fundamental laws two decades later. Newton's idea of universal gravity two decades later helped him create a general system of classical mechanics [Gorelik, 2023]. Maxwell, having discerned the concept of an electromagnetic field in Faraday's "lines of force", built a fundamental system of laws of electromagnetism, and as a "reward" he discovered the electromagnetic nature of light. The "rewards" of quantum and relativistic concepts are well known.

The Galilean way of advancing science became the most powerful engine in modern physics. The triumphal success of Newton's advances was also an inspiration to other natural sciences. The concepts of atoms in chemistry (~1800), discrete material units of heredity in biology and movable continents in geology (~1900) were no less hidden, invisible and "illogical" than Newton's gravity.

This new way of advancing science also manifested itself in unsuccessful theories. One could say that the concepts of phlogiston and caloric fluid were simply "not crazy enough" as they were invalidated by new experiments.

Unlike ancient *philosophical* inventions such as *apeiron*, *aether* and *atoms*, all the "crazy enough" fundamentals in modern physics were invented in order to describe and explain quite specific observable *physical* phenomena.

The Origin of Modern Science Is the Origin of Modern Physics

In 2015, the origin of modern science became the main subject of two books: *To Explain the World: The Discovery of Modern Science*, by the physicist (and Nobel Prize winner) S. Weinberg [2015], and *The Invention of Science: A New History of the Scientific Revolution*, by the historian D. Wootton [2015]. Both advocated the notion of "the Scientific Revolution" (of the 16–17th centuries) with modern science as its result, both saw its origin as "astro-physical", albeit they significantly differed in their historical scenarios. For Weinberg, "*Whatever the scientific revolution was or was not, it began with Copernicus*", and it was Galileo, who "*provided a paradigm for modern experimental physics*". For Wootton, the revolution began in 1572 with Tycho Brahe, and "*the first true science*" was astronomy.

Neither Weinberg nor Wootton provided an explicit definition of "modern science", while both emphasized the key role of *experimental* verification. Here again one can see the key difference between modern physics and the perfectly scientific theories of the great Greeks. Euclid's geometry and Archimedes' physics made their *experimental* verification somewhat redundant because their axioms were based on "self-evident" everyday experience. The corollaries – geometrical and physical theorems – logically derived from those axioms evidently needed no empirical verification, if the logic of derivation had not been broken. As for the "crazy enough" fundamentals of modern science, they were so far from self-evident that the only way to justify them was to test the statements about specific physical phenomena logically deduced from the fundamentals in as many experiments as necessary to prove fundamentals beyond reasonable doubt.

Weinberg wrote that he first thought of using "The Invention of Modern Science" as a subtitle, but chose "discovery" instead of «invention» to express his understanding of epistemology of science. On the other hand, Wootton, quoting Weinberg's book and sharing his epistemology, chose the word "invention". Since science as a system of convincing objective knowledge was invented in ancient Greece, the first subtitle that Weinberg had in mind seems to be more adequate.

The notions of "invention" and "discovery" are actually interconnected and peacefully coexist in the history of modern physics. Before discovering that a new fundamental theory was possible, modern physicists had to invent "crazy enough" fundamental concepts – a radically new words, or rather notions, in science. Those conceptual words were used to formulate new fundamental postulates which were "*not logically derivable from what is empirically given*" but testable in experiments.

Galileo was not the first to dare to deal with concepts of invisible – "*unobserved and the unobservable*", and he might have been encouraged by the fruitfulness of "absurd" astro-mathematical heliocentrism of Copernicus. But Galileo was the first to successfully demonstrate a new way of investigating material world by "*a systematic change in intellectual outlook, in the type of question asked*" and in the experimental answers he sought. Thus, he did deserve to be nominated by Einstein for the title "*the father of modern physics*".

To dare to '*the boldest speculation*', to overcome the 'self-evident absurdity' of a new 'crazy' concept, the fundamental inventor had to rely on some convincing (for him personally) observable phenomena related to the new fundamentals, long before a full-fledged theory.

For Copernicus, the 'absurd' concept of heliocentrism was justified by phenomena as observable from the "solar point of view": the absence of retrograde motion of the planets, their order around the Sun, the increase in their periods of revolution with distance from the Sun, the proximity of Venus and Mercury to the Sun, as observed from the Earth. For Galileo, the anti-Aristotelian physical concept of vacuum was justified by his experiments with inclined planes and pendulums. And for Newton the absurd concept of universal attraction was justified by the connection of the Moon's motion and the movement of a projectile he discovered in 1666 [Gorelik, 2023].

Those justifications, however, were not convincing to majority of colleagues of the first fundamental inventors because of inertia of thinking, supported by the authority of Aristotle and Ptolemy. Galileo and Kepler were among the tiny minority who accepted Copernicus's "boldest guess" as the actual physical truth, despite the lack of a physical explanation for why the Earth's motion (at a speed of 30 km/s!) had no observable manifestations. At the same time, the great astronomer T. Brahe, who appreciated the computational advantages of the Copernican system, "neutralized" its physical heliocentrism.

Fundamental inventive boldness is rooted in the mysterious depth of "*the human spirit*" (aka intuition), beyond normative scientific logics. In this depth, in the words of Einstein, "*Our moral leanings and tastes, our sense of beauty and religious instincts, are all tributary forces in helping the reasoning faculty towards its highest achievements.*"

The history of successful 'crazy' fundamental inventions in the first century of modern physics was an inspiration for fundamental inventors in the space-time of quantum-relativistic revolution of the 20th century.

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