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COULD GALILEO DISCOVER THE LAW OF UNIVERSAL GRAVITATION IN 1611, WAS THERE NEWTON'S APPLE AND WHAT IS "MODERN PHYSICS"?

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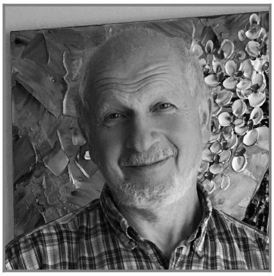

The central problem of the article is the paradox in the history of Newton's mechanics: prominent researchers of the genesis of the Principia did not believe Newton's words about the origin of the idea of universal gravity. They did not believe that he could have come up with this idea as early as 1666, considering circular orbits, and believed that Newton invented the story of the falling apple. The article proposes a "subjunctive" scenario leading to the law of universal gravity and feasible at the level of Galileo's knowledge and skills in 1611. The basis for such a scenario is the description of a thought experiment in Newton's manuscript "The System of the World", preceding the creation of Principia. The proposed reconstruction helps to consider and clarify the concept of "modern physics", the birth of which was the main event of the Scientific Revolution of the XVI–XVII centuries. The traditional understanding reduces the essence of modern physics to a reliance on experience and on the language of mathematics. Such a definition, however, is not sufficient. The geometry of Euclid and the physics of Archimedes were mathematically perfect, and their axioms were based on objective experience. Despite the importance of the tools of mathematics and experiment, the key innovation of modern physics has become the belief in the hidden fundamental laws of the Universe and in the right of the researcher to invent invisible, "illogical", "absurd" concepts and postulates, experimentally verifiable only together with the theory based on them. This postulate of fundamental cognitive optimism combines bold ingenuity with a humble need for empirical verification.

Keywords: modern physics, theory of gravity, fundamental concepts, Newton's apple, cognitive optimism

МОГ ЛИ ГАЛИЛЕЙ ОТКРЫТЬ ЗАКОН ВСЕМИРНОГО ТЯГОТЕНИЯ В 1611 ГОДУ, БЫЛО ЛИ ЯБЛОКО НЬЮТОНА И ЧТО ТАКОЕ «СОВРЕМЕННАЯ ФИЗИКА»?

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Центральная проблема статьи – парадокс в истории механики Ньютона: видные исследователи генезиса "Principia" не поверили словам Ньютона о зарождении идеи всеобщей гравитации. Не поверили, что он мог прийти к этой идее еще в 1666 г., рассматривая круговые орбиты, и считали, что историю о падающем яблоке Ньютон придумал. В статье предложен «сослагательный» сценарий, приводящий к закону всеобщей гравитации и осуществимый на уровне знаний и умений Галилея еще в 1611. Основание для такого сценария дает описание мысленного эксперимента в рукописи Ньютона “The System of the World”, предшествующей созданию “Principia”. Опираясь на предложенную реконструкцию, рассматривается и уточняется понятие «современной физики», рождение которой стало главным событием Научной революции XVI–XVII вв. Традиционное понимание сводит суть современной физики к опоре на опыт и на язык математики. Такое определение, однако, недостаточно. Геометрия Евклида и физика Архимеда были математически совершенны, а их аксиомы опирались на объективный опыт. При всей важности инструментов математики и эксперимента, ключевой новацией современной физики стала вера в скрытые фундаментальные законы Вселенной и в право исследователя изобретать невидимые, «нелогичные», «абсурдные» понятия и постулаты, экспериментально проверяемые лишь вместе с основанной на них теорией. Этот постулат фундаментального когнитивного оптимизма соединяет смелую изобретательность со смиренной потребностью в эмпирической проверке.

Ключевые слова: современная физика, теория гравитации, фундаментальные понятия, яблоко Ньютона, когнитивный оптимизм

1. Riddles of Nature and Riddles of the History of Science

Having seen the title of this article, few people would not recall that “history does not know the subjunctive mood.” History may not know, but a historian who wants not only to register the “bare facts” of the past, but to comprehend their connections, inevitably asks himself subjunctive questions. Thinking about them, one can better understand the real course of history, see causal relationships, distinguish necessary conditions from sufficient ones, and fortunate set of contingencies from insignificant coincidence.

Causal relationships, the main goal in physics, are much less visible in its history. And the riddles of the history of science are no easier than the riddles of nature. On the global historical scale, the uneven development of natural science is especially mysterious. Three powerful upsurges of scientific activity and two declines were clearly separated in time (by centuries) and in (cultural) space. Classical Antiquity gave the miracle of Greek science, the highest achievements of which are the geometry of Euclid and the physics of Archimedes. The golden age of Islam gave Arabic-speaking science, which, mastering the heritage of Antiquity, India and China, introduced its own innovations that live in the current scientific terminology. Finally, basing on both of these heritages, Europe of the 16th–17th centuries gave modern physics, the main mystery of which is that until the 20th century it developed only in the European cultures. This riddle was most acutely formulated and researched by J. Needham, who never found a convincing "causal" solution [Needham, 2000; Gorelik, 2018].

Thousands of books and articles have been devoted to the birth of modern physics (aka "Scientific Revolution"). A huge amount of factual material has been accumulated and many explanations have been proposed, the very variety of which speaks of their weakness [Cohen, 1994]. Lives of prominent scientists of the XVI–XVII centuries have been studied in great detail, but their motivations and mutual influences leave important questions.

Why, for example, Kepler and Galileo enthusiastically accepted the heliocentrism of Copernicus, while Tycho Brahe, the greatest astronomer-observer of the 16th century, having accepted the calculating advantages of the Copernican system, "neutralized" its heliocentrism, obeying "common sense", like most of the then scientific community? Why didn't Galileo take Kepler's planetary laws seriously, implying only circular orbits of the planets? And why did Galileo, having obtained his main scientific results by 1609, postponed their publication (for thirty years!) and made great efforts to advocate the theory of Copernicus? Despite his own position, expressed in a 1597 letter to Kepler:

> Like you, I accepted the Copernican position several years ago… I have written up many reasons and refutations on the subject, but I have not dared until now to bring them into the open, being warned by the fortunes of Copernicus himself, our master, who procured for himself immortal fame among a few but stepped down among the great crowd (for this is how foolish people are numbered), only to be derided and dishonored. I would dare publish my thoughts if there were many like you; but, since there are not, I shall forbear [quoted in G. de Santillana, Crime of Galileo, 1962, p. 7].

Particularly strange, if not to say "scandalous", is the situation around Newton. Prominent historians who studied the genesis of Newton's mechanics (set out in his famous "Philosophiæ Naturalis Principia Mathematica", hereafter Principia), did not believe his words about the origin of the idea of universal gravity. They did not believe that Newton could come to this idea back in the 1660s, considering circular orbits. They didn't believe in the story of falling apple. Here are some quotations:

> Newton devoted much time and energy to composing and advancing a chronology of his discoveries that would place many of them at an earlier date than the primary historical documents would warrant to successfully combat his opponents in the controversies that arose over priority. Newton may have invented the story of the apple, which would be dated in the mid-1660s, when he alleged he had made the moon test. We know that he himself told the story of the apple's falling, the origin of the oft-repeated statement that this was the occasion for his thinking about gravity's extending to the moon [Cohen, 1992, p. 227].

> We should not take for gospel the tales that Newton was wont to tell in his old age of how a falling fruit (be it an apple or no) had led him as a young man to ponder whether all motion, in the heavens no less than on Earth, is governed by some principle of universal gravitation. Maybe so, but nothing in his own papers supports it. […] All such stories, even when told by Newton about himself, must be submitted to the usual canons of historical evidence, and when they do not pass, then they must be demoted to being mere unsupported anecdote [Whiteside, 1991, p. 18].

Within the philosophy of science, Newton's *"claim to have "deduced" the law of universal gravity from phenomena of orbital motion" was claimed to be "at best misleading and at worst a subterfuge"* [Harper, 2016, 229].

To sum up, and to put it simply, Newton lied to secure his priority and worldly glory. Really?

A polite answer to this impolite question is that the apple was not mentioned at all in the 2005 "Open forum" discussion [Newton vs Hooke on gravitation, 2005].

2. How Far From an Apple Tree Can an Apple Fall?

The riddles of the 16th and 17th centuries challenged me for the first time twelve years ago. Dealing with the history of fundamental physics in the 20th century, I wanted to understand why Einstein called Galileo *the father of modern physics* [Einstein, 1960, p. 271]. Why exactly did a 20th-century physicist feel close to a man who lived three centuries before him and knew almost nothing of what Einstein learned in high school?

Reading the texts of Galileo through the eyes of an experienced historian, I tried to understand at what time it was written and what science did not yet know then. Not knowing at first even such simple concepts as speed and acceleration, Galileo thought like a real modern physicist, developing new concepts, based on the experience of the experimenter and the inventive thinking of the theorist.

This was the beginning of my expedition in the times from Copernicus to Newton, and the above-mentioned questions began to arise with no convincing answers in the literature.

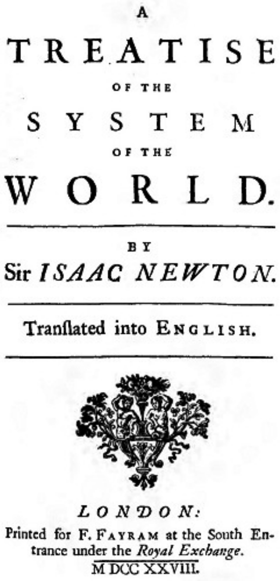
Of course, I heard about the Newton's apple, but I had no idea how the fall of a ripe apple could be connected with the Moon hanging overhead. There was an excuse at hand that a genius sees something that mere mortals cannot see. But, seriously plunging into the affairs of bygone centuries, I wanted to see the primary sources of this story.

There are two testimonies of people close to Newton that he, in the last years of his life, told them about the apple. The most detailed, recorded 25 years after Newton's death, conveys his thoughts as follows:

> "Why should that apple always descend perpendicularly to the ground," thought he to him self: occasion'd by the fall of an apple, … "Why … not go sideways, or upwards? … There must be a drawing power in matter." …That there is a power like that we here call gravity which extends its self thro' the universe & thus by degrees, he began to apply this property of gravitation to the motion of the earth, & of the heavenly bodys… [Stukeley, 1752].

The author of this testimony was just an antiquarian. So his description of the thought process of the great physicist can be neglected. All that remains is the fact that Newton told him about a funny scientific clue and somehow explained the flight of his thoughts from an apple to heavenly bodies. But how? How can a falling apple be associated with the constantly hanging, though not suspended, Moon?

I found a historical and scientific clue from Newton himself, when I saw a picture in his manuscript, completed two years before the publication of his Principia (1687), and published in 1728, a year after the death of the author:

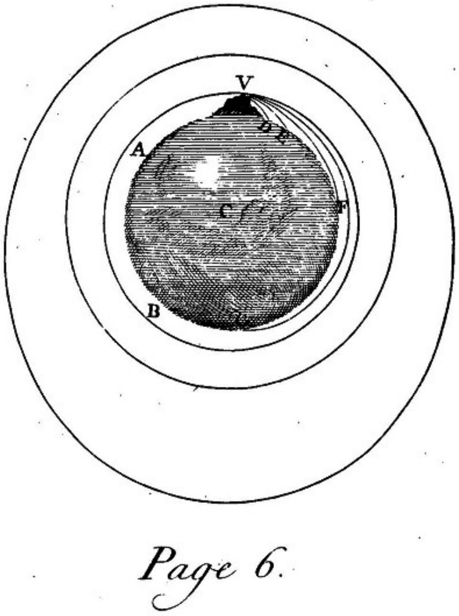


A
TREATISE
OF THE
SYSTEM
OF THE
WORLD.

BY
Sir *ISAAC NEWTON.*

Tranſlated into ENGLISH.

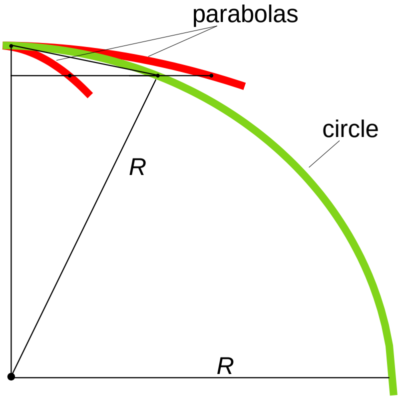
LONDON:
Printed for F. FAYRAM at the South Entrance under the *Royal Exchange.*
M DCC XXVIII.



> Let AFB represent the surface of the earth, C its centre, VD, VE, VF, the curve lines which a body would describe, if projected in an horizontal

> direction from the top of an high mountain successively with more and more velocity; and, because the celestial motions are scarcely retarded by the little or no resistance of the spaces in which they are performed, to keep up the parity of cases, let us suppose either that there is no air about the earth, or at least that it is endowed with little or no power of resisting; and for the same reason that the body projected with a less velocity describes the lesser arc VD, and with a greater velocity the greater arc VE, and, augmenting the velocity, it goes farther and farther to F and G, if the velocity was still more and more augmented, it would reach at last quite beyond the circumference of the earth, and return to the mountain from which it was projected [Newton, 1846, web].

The figure shows a globe with a high mountain on it. Projectiles are thrown (or shot by a cannon) from the mountaintop in a horizontal direction with increasing speed and corresponding trajectories, one of which is a circumnavigation. Remembering Newton's apple, I realized that it could fall not "perpendicularly to the ground" if the day was windy, and the wind was gusty enough to pick a ripe apple from a branch. This apple fell along the parabola prescribed by Galileo, and the young physicist Newton might ask himself with what speed the wind should throw the apple (or the cannon – shoot the ball) so that it, falling, remains at the same distance from the surface of the earth, curving under it. Galileo himself could well have asked himself a similar question, having discovered the law of free fall by 1610 [Drake, MacLachlan, 1975]. Putting myself in the Galileo's shoes, with his knowledge and skills, I realized with amazement that the answer to such a question could lead him to the discovery of the law of universal gravitation as early as 1611, when he had already made his telescopic discoveries [Gorelik, 2012; 2013, pp. 66–67].



This is how Galileo could reason. The width of the projectile's parabolic trajectory depends on its initial speed. Comparing the parabola with the circular (circumnavigation) orbit in the "first moment" after the throw and requiring the smallest difference, he could get the value of the necessary speed by neglecting air resistance (which he did a long time ago) and using only elementary mathematics:

$$V= (gR)^{1/2},$$

where g is the acceleration of free fall (measured and legitimized by Galileo), and R is the radius of the orbit, which practically coincides with the radius of the Earth. Using numerical values, he would get $V_{ASE} = (gR_E)^{1/2} \approx 8$ km/s (hereinafter, for clarity, just to show the course of reasoning, modern rounded values are taken; historical values differed, but much less than an order of magnitude).

Galileo did not know the expression "artificial satellite of the Earth" (abbreviated as ASE), but he would have easily figured out that the flight of a projectile around the globe is very similar to the motion of the Moon. And he would check the resulting formula by substituting the radius of the Moon's orbit into it:

$$\{?\}\ V_M = (gR_M)^{1/2} \approx 60 \text{ km/s}.$$

However the real speed of the Moon, which is easy to calculate by dividing the length of the lunar orbit by the lunar month,

$$V_{Me} \approx 1 \text{ km/s}.$$

Reflecting on this discrepancy, the physicist Galileo might well have thought that he had measured the acceleration g on the surface of the Earth, and not near the Moon, at a distance of 60 times the radius of the Earth. He would ask himself: What should be the acceleration of free fall at a lunar distance from the Earth in order to get the observed speed of the Moon? And he would get that

$$\{?\}\ g_M \approx g_E/3600.$$

3600 is too close to the square of the ratio $R_E/R_M \approx 60$, so that Galileo would not notice this and would not suggest that

$$g(R) = A/R^2,$$

where A is some constant that can be expressed in terms of the observed values of the orbit radius R and the period of revolution T:

$$A = gR^2 = RV^2 = 4\pi^2R^3/T^2$$

Having connected in this way the motions of the two satellites of the Earth – a thought artificial one and the only natural one, Galileo could not help but recall the two sets of satellites of two other celestial bodies – the satellites of Jupiter that he had just discovered and the long-known planets in which he would easily recognize the satellites of the Sun, since long ago he accepted the Copernican system.

In each of these two sets, he could compare the motions of different satellites (using the radii of their orbits and periods of revolution) and check whether they have the same constant A. Indeed, for each set of satellites, the value of A would be approximately the same, but in different sets the values of A would differ very much. From the then astronomical data, Galileo could calculate that

$$A_{\text{Jupiter}} \approx 300\ A_{\text{Earth}},\ A_{\text{Sun}} \approx 300\ 000\ A_{\text{Earth}}.$$

It would be natural to assume that the value A characterizes the central celestial body of the set – the Earth, Jupiter and the Sun. These three celestial bodies differ astronomically (for their satellites) in size, mass ***M*, *as the amount of matter***, and luminosity. A physicist would suggest that the key difference is the amount of matter, i.e.

$$A = GM,$$

where the constant G is the same for the Earth, Jupiter and the Sun and, judging by this, for any other body.

The constant G could be estimated by considering the average density of the Earth close to the density of its solid rocks (~ 3×10^3 kg/m³). Then the world constant $G \approx 10^{-10}\ \text{m}^3\ \text{s}^{-2}\ \text{kg}^{-1}$ (the current value of $G = 0.7\times10^{-10}\ \text{m}^3\ \text{s}^{-2}\ \text{kg}^{-1}$).

So, by astro-physical reasoning, Galileo could discover the ***Universal Law of Free Fall***

$$g\,(R) = GM/R^2,$$

which determines the acceleration of free fall at a distance R from a celestial globe of mass M. Thus, **Galileo would need neither the concepts of force and mass (as measure of inertia), nor Kepler's laws, nor higher mathematics. His law of free fall would be enough.**

From here the path to Newton's theory of gravitation was opened, though to pass this path, the mathematical power of the great British physicist was needed. On a qualitative level, however, the Universal Law of Free Fall would have prepared a lot and, above all, would have helped Galileo to overcome his rejection of the very notion of "attraction", which was used by Kepler without physical justification:

> When the moon is located directly above the [ocean] it attracts the waters clinging to the sphere of the earth. The effect of this attraction is that from all sides the waters rush to the huge area which is directly below the moon and is not closed off by the continents, so that the shores are exposed [Kepler, 2003, pp. 69–70].

Such an explanation, which now seems to be a simple description of the cause of the tides, in the eyes of Galileo, was a relic of occultism:

> Among all the great men who have philosophized about this remarkable effect [tides], I am more astonished at Kepler than at any other. Despite his open and acute mind, and though he has at his fingertips the motions attributed to the earth, he has nevertheless lent his ear and his assent to the moon's dominion over the waters, to occult properties, and to such puerilities [Galilei, 1953, p. 462].

The ***Universal Law of Free Fall*** would have helped Galileo to put a new – physical – meaning into Kepler's words. After all, if any large Globe M causes projectiles in its vicinity to fall freely towards the center of this Globe with an acceleration $g(R) = GM/R^2$, then in Kepler's laws one can see not only mathematically elegant empirical relationships which do not follow from physics. Of course, there is no solar force driving, according to Kepler, the planets, but free fall with an initial speed at an angle to the radius **R** (connecting the projectile to the center of the Globe) is sufficient for the physical derivation of the laws of planetary motion. If the angle is 90°, then it is easy – for circular orbits – to obtain (and refine) Kepler's third law $T^2 \sim R^3$ (more precisely, $R^3/T^2 = GM/4\pi^2$). If the angle is smaller or larger than 90°, then it would be more difficult to suspect and even more so to prove that the circle will turn into an ellipse, but it would be easier to accept the hint of Kepler's first law. And so Galileo would have realized that his parabolas are just the tips of very narrow ellipses.

He would also understand that Kepler's laws are only approximate. A projectile that is between (or next to) two large Globes must move under their joint action – fall freely to the centers of two Globes at once. Knowing the concept of compound motion, Galileo could "add" both accelerations of free fall, taking into account different directions (vectors, in the current language) and would have received a trajectory that is not at all like an elliptical one.

Launching a thought satellite at different distances from the Earth and reaching close to the Moon, the question would arise: is it still a satellite of the Earth or already a satellite of the Moon? From this question it would follow that Kepler's laws are approximate, they are the more accurate, the farther all the large Globes are from the "Central" one.

Whether to replace the words "Free Fall" with the word "Gravitation" is a matter of terminology. Much more important for Galileo would be to justify his belief in the physical unity of the sublunary and supralunary worlds, since the cause of the free fall on the surface of the Earth and the cause determining the orbits of the planets turned out to be the same.

In the end, Galileo would see that he was right, taking as a model of planetary motion not an empirical ellipse, but a theoretically simplest circular orbit. He did not know Einstein's advice "Everything should be made as simple as possible, but not simpler", but Galileo's model was quite consistent with this advice, since it allowed him to go from terrestrial free fall to celestial universal gravitation.

It would be worthwhile to complete the subjunctive history with the question: Why did Galileo not take the opportunity to make another great theoretical discovery? A more general question should be added: Why did Galileo, having postponed the publication of his main scientific results, devoted himself to promoting the theory of Copernicus? A sketchy answer to both questions can be seen in the fact that in 1610 Galileo was fortunate to make stunning observational astronomical discoveries that supported the theory of Copernicus, in his opinion, clearly and convincingly. And he, in gratitude for the good fortune bestowed upon him, assumed the responsibility of explaining the teachings of Copernicus to his contemporaries. That he overestimated the persuasiveness of the arguments and underestimated the "number of fools", he understood not very soon.

Applying the suggested subjunctive history to real history, I would hypothesize that if the transition from the terrestrial law of free fall to astronomical laws was feasible at the level of knowledge and skills of Galileo back in 1611, then it was feasible half a century later to Newton, who "stood on the shoulders of giants" and was himself a giant in both physics and mathematics. This hypothesis is supported by the abovementioned description of a thought experiment in Newton's manuscript of 1685, which somehow was ignored by historians of Principia.

3. The Historical Riddle of the Newton's Mechanics and the Essence of "Modern Physics"

The main historical riddle of Newton's mechanics may be the fact that prominent historians rejected his testimonies about the beginning of this history. Here is how, for example, the preface to the publication of Newton's mathematical manuscripts begins:

> Even though Newton himself, half a century afterwards, preferred to look to the two 'plague years' of 1665 and 1666 as the 'prime' of his 'age for invention' when he 'minded Mathematicks & Philosophy more then at any time since', the dozen and a half months from August 1684, when Edmond Halley first travelled to Cambridge to seek his opinion on the currently vexing question of how dynamically to determine the closed orbits of the planets round the sun, have (so it seems to us) an overriding claim to be regarded as the most deeply fruitful annus mirabilis of Newton's life [Whiteside, 1974, p. vii].

There was a legendary note of an expert in Goethe studies to the poet's phrase that his greatest love was Gretchen. The expert corrected: "Here Goethe was mistaken, his greatest love was Lizhen."

Delving into the texts of historians of Newton's mechanics, I realized that the matter is much more serious, "more scientific." To reconstruct thinking of the genius, the historians carefully examined the surviving manuscripts, relying on their understanding of the achievements of the genius and on their own "silent" implicit premises.

One of the main premises is the idea of what "modern physics" is, how it differs from the highest achievements of ancient science – the geometry of Euclid and the physics of Archimedes, which have retained their validity to this day actually without need to be corrected.

According to the traditional understanding, modern physics is distinguished by a reliance on experiment and mathematical language. J.Needham defined modern science as "*the combination of mathematized hypotheses about natural phenomena with relentless experimentation*" [Needham, 2004, p. 1]. However, in the words of prominent biographer of Newton,

> Historians of science are almost unanimous in making what Alexandre Koyre called the "mathematization of nature" one of the central, perhaps the most central characteristic of the Scientific Revolution [Westfall, 2001, p. 321].

Indeed, historians of Principia focus their attention on the mathematical side of the monumental work published in 1687, on the history of its system of axioms and theorems [Whiteside, 1974]. The question is where to begin the history of this triumphant completion of Galileo's ideas and experiments.

The physicist Einstein, calling Galileo "*the father of modern physics*", emphasized the role of experiment:

> Pure logical thinking cannot yield us any knowledge of the empirical world; all knowledge of reality starts from experience and ends in it. Propositions arrived at by purely logical means are completely empty as regards reality. Because Galileo saw this, and particularly because he drummed it into the scientific world, he is the father of modern physics… [Einstein, 1960, p. 271].

Newton called for the combination of both instruments:

> Truly with the help of philosophical geometers and geometrical philosophers, instead of the conjectures and probabilities that are blazoned about everywhere, we shall finally achieve a science of nature supported by the highest evidence [Quoted in: Smeenk, 2016].

Justification is the end of a scientific search, but "dashing trouble is the beginning." Speaking of this beginning, Einstein actually supported Newton's view, correcting himself twenty years later and adding an important feature:

> It has often been maintained that Galileo became the father of modern science by replacing the speculative, deductive method with the empirical,

> experimental method. I believe, however, that this interpretation would not stand close scrutiny. There is no empirical method without speculative concepts and systems; and there is no speculative thinking whose concepts do not reveal, on closer investigation, the empirical material from which they stem. To put into sharp contrast the empirical and the deductive attitude is misleading, and was entirely foreign to Galileo… Moreover, the experimental methods at Galileo's disposal were so imperfect that only the boldest speculation could possibly bridge the gaps between the empirical data [Galilei, 1953, p. xix].

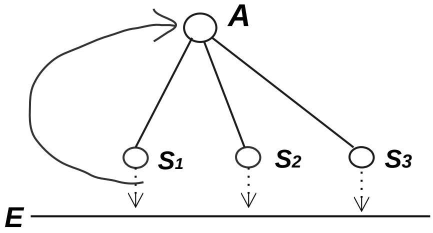
The right to "*the boldest speculation*" is the key difference between modern physics and the greatest achievements of classical antiquity – the geometry of Euclid and the physics of Archimedes, which "mathematized" nature and were based on experience no less than modern physics. Both ancient Greek theories were mathematically perfect and gave examples of an axiomatic system of convincing knowledge, which remains an ideal in modern physics. At the same time, the basic – not formally defined – concepts and axioms were taken from visually obvious experience of land measuring and lever-balance weighing: *point*, *straight line*, *lever*, along with their axiomatic properties.

In modern physics, however, the fundamentals of new theories were far from obvious for the colleagues of the inventors of these fundamentals. To distinguish the new status of fundamentals, hereafter they will be called *fundamental concepts* and *postulates*.

Einstein emphasized that the fundamental concepts of modern physics are *"free inventions of the human spirit (not logically derivable from what is empirically given)"*, and that *"unless one sins against logic, one generally gets nowhere"* [Einstein, 1949, p. 684; 1993, p. 147]. Apparently he was referring to the logic of science or common sense at the time of the invention.

The same idea was expressed by Niels Bohr when discussing a plan of a new fundamental theory: *"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].

Einstein presented his understanding of the development of modern physics by a diagram [Einstein, 1993, p. 137]



Here the arc is illogical takeoff of inventive intuition to the axioms ***A***. The runway of intuition is experience ***E***. If the statements $\boldsymbol{S_n}$, logically deduced from the axioms, can be "softly landed" in (confirmed by) experience, the entire scientific enterprise is justified.

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 resolve such results and/or contradictions, new fundamentals will have to be invented again and connected with the previous fundamentals by a specific correspondence. And the next cycle of development will begin according to Einstein's scenario.

In the history of modern physics, there were, as far as I can see, only eight such "illogically" successful fundamental inventors – "The Magnificent Eight". The first two were, actually, astro-mathematicians rather than physicists: Copernicus' heliocentrism was pure astro-mathematics, while Kepler accompanied his planetary laws by "groping" their physical origin. Galileo invented the physical concept of vacuum, which let him come to three fundamental laws – the law of inertia, the principle of relativity and the law of free fall. Newton invented the concept of universal gravitation, and in the course of creating the theory of gravitation, he built a system of classical mechanics.

Then, after a two-century pause, Maxwell invented the concept of an electromagnetic field, Planck – quanta of energy, Einstein – the absoluteness of the speed of light, quanta of light, and curved space-time, Bohr – quantum states. Each of these inventions opened up great opportunities for expansion of scientific knowledge, "rewarding", sometimes years and decades later, with unexpected remarkable discoveries: the electromagnetic nature of light, the theory of the photoelectric effect, relativistic astrophysics, physical cosmology, quantum theory.

The intuition of a fundamental inventor finds in the experience of science an opportunity to invent a new "illogical" (and even absurd for non-inventors) concept that would let to formulate a new postulate and to construct a new fundamental theory that explains a challenging experiment and/or resolves a challenging contradictions on theory.

In modern fundamental physics, the meaning of reliance on experience has qualitatively changed compared to the sciences of Euclid and Archimedes, where all concepts and axioms were taken from ordinary – visible and tangible – experience and were "self-evident". Therefore, the theorems derived from such axioms were no longer required to be verified (if the logic was not violated during the derivation). On the other hand, in modern physics, the empirical verification of new "theorems" is the only way to verify the invented postulates together with the new fundamental concepts.

The history of physics, of course, could not be reduced to the inventions of new fundamental concepts and postulates. Applying them to new phenomena required enormous efforts by outstanding physicists (many more than eight) and led to astonishing applications both in science and technology. And yet, it is precisely the breakthrough inventions of new – "crazy enough" – fundamentals that is the key distinction and the most powerful engine of modern physics.

It is not about new words, but about new fundamental ***physical*** concepts, basing on which a new ***mathematized*** theory is able successfully describe physical reality, where success is judged by experiments.

The idea of heliocentrism, for example, was pronounced already in Ancient Greece, but it was a ***philosophical*** concept, not aimed at describing specific physical phenomena to be verified quantitatively. And this astro-philosophical idea was rejected as absurd by the ancient astronomers. So more difficult it was to resurrect this idea as a postulate, from which Copernicus obtained important observational consequences. True, they were observational for those who dared to mentally look at the Universe from the "solar point of view". The magnificent inventors Kepler and Galileo had the courage to allow themselves such a mental journey, but not the "king" of observational astronomy Tycho Brahe.

The word "attraction" was also pronounced by astronomers before Newton, starting with Kepler. But it was only a vaguely descriptive word, in which Galileo saw just a relic of an astrological past. The concept of *universal gravity* seemed *absurd* not only to such great scientists as C. Huygens and G. Leibniz, but also to Newton himself – even 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, pp. 472, 505]. (Newton's intuition was competent enough, since in Einstein's theory of gravity the 'agent acting constantly according to certain laws' – the geometry of space-time – was neither material nor immaterial.)

Another important example is the fundamental concept of the atom, which came to physics not from ancient Greek philosophy (where the word "atom" was invented), but from English chemistry at the beginning of the 19th century. The triumphant success of the English invention of "invisible" gravity might help in the invention of "invisible" atoms. The resistance of some prominent physicists to this invention was overcome by its fruitfulness.

The new way of inventing fundamental concepts manifested also in the unsuccessful theories of phlogiston and caloric fluid. These inventions were invalidated by new experiments that expanded the empirical runway ***E*** at Einstein's diagram.

In contrast to ancient philosophical inventions like apeiron, aether and atoms, all the 'crazy enough' fundamentals in modern physics were invented in order to describe and explain specific observable natural phenomena.

4. So Did Newton Make His Main Invention in 1666?

Let's return to the 24-year-old Newton in the plague year of 1666 and to his apple insight, so doubtful for prominent historians.

The way suggested in §2 to take off from the earthly law of free fall to the concept of universal gravitation may seem quite logical and feasible only to those who, in their school years, got acquainted with the idea of universal gravitation and was accustomed to launching artificial satellites. As for Galileo and Newton, the invisible "immaterial" action at a distance was too reminiscent of astrological "influences" to dare to introduce it into the arsenal of physics. Such inventions are only possible for a uniquely gifted person with a uniquely strong character, who relies on boldly thought-out experience, builds on it and… takes off on his intuition.

Creative intuition is a mysterious combination of a person's cultural resource, personal experience and personal genetics. According to Einstein:

> 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 believe in intuition and inspiration… 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 [Einstein, 1930, p. 375; 1931, p. 97; Cohen, 2017].

Historians of science use the concept of "intuition" only after they have exhausted the documented circumstances of the discovery-invention. This concept is deeply individual and is associated with a type of thinking that can significantly distinguish one creative person from another. An example of such a difference is the "bird" and "frog" styles described by F. Dyson [Dyson, 2015].

There is testimony of Newton himself about the events of 1665–66, written in 1718 (in response to a request from a French translator). According to Newton, having received striking results in mathematics and optics in 1665 and the first half of 1666, he took up gravity:

> And the same year I began to think of gravity extending to [the] orb of the Moon & having found out how to estimate the force with [which]

> [a] globe revolving within a sphere presses the surface of the sphere from Keplers rule of the periodical times of the Planets being in a sesquialterate proportion of their distances from the centers of their Orbs, I deduced that the forces [which] keep the Planets in their Orbs must [be] reciprocally as the squares of their distances from the centres about [which] they revolve: & thereby compared the force requisite to keep the Moon in her Orb with the force of gravity at the surface of the earth, & foun them answer pretty nearly. All this was in the two plague years of 1665 & 1666. For in those days I was in the prime of my age for invention & minded Mathematicks & Philosophy more then at any time since [Whiteside, 1966, p. 32].

Basing on other evidence about the evolution of Newton's mathematical ideas, the publisher of his manuscripts wrote: *"we must agree that [Newton's] description of his earliest calculus researches is essentially accurate"*, although some details *"we will find more difficult to justify and may choose to ignore"* [Whiteside, 1966, p. 35].

As for the idea of universal gravitation, according to historians of Newtonian mechanics, no other real evidence of the origin of this idea has been found, *except for four testimonies* about stories that Newton told people close to him in the last years of his life. But historians almost unanimously do not consider this evidence – "have chosen to ignore."

They also ignore the evidence published in 1728, in the first version of Newton's System of the World, a description of a thought experiment on a mountaintop. Apples can fall not only strictly vertically, but also along Galilean parabolas, if a gusty wind helps. The trajectories on the experiment diagram show a smooth transition from terrestrial parabolas to an astronomical circular orbit.

A falling apple blown by the wind could be a great clue. And the importance that Newton attached to the law of free fall was manifested in the fact that in Principia this law with the name of its author is mentioned nine times. And the physicist Newton, knowing that real astronomical orbits are ellipses, began, like the physicist Galileo, with circular orbits.

In Principia, Newton explained why he changed his mind about publishing the first version of his System of the World:

> Upon this subject ["the System of the World"] I had, indeed, composed the third Book in a popular method, that it might be read by many; but afterward, considering that such as had not sufficiently entered into the principles could not easily discern the strength of the consequences, nor lay aside the prejudices to which they had been many years accustomed, therefore, to prevent the disputes which might be raised upon such accounts, I **chose to reduce the substance of this Book into the form of Propositions** (in the mathematical way), which should be read by those only who had first made themselves masters of the principles established in the preceding Books [Newton, 1846, web].

The first version of the “System of the World”, starting with the ancient Greeks, looks like the first (rather than third) part of the Book *“composed in a popular method”*. In this version the thought experiment discussed above is the very first physical and mathematical reasoning, and it is preceded by a clear “declaration of intent”:

> *The later philosophers pretend to account for* [the motions of planets] *either by the action of certain vortices, as Kepler* and *Des Cartes*; or by some other principle of impulse or attraction, as *Borelli*, *Hooke*, and others of our nation; for, from the laws of motion, it is most certain that these effects must proceed from the action of some force or other. **But our purpose is only to trace out the quantity and properties of this force from the phænomena, and to apply what we discover in some simple cases as principles**, by which, in a mathematical way, we may estimate the effects thereof in more involved cases [Newton, 1846].

This declaration makes the visual thought experiment even more powerful evidence of its “apple” hint. And it is all the more surprising that prominent historians, when discussing the origin of Newton’s theory of gravity (and classical mechanics in general), ignored this evidence, in fact accusing Newton of the deliberately false fabrication to protect his priority.

One reason for this attitude may be that those historians have taken ***too much credit for the literal accuracy*** of Newton’s 1718 laconic testimony (quoted above) about his thoughts in 1666 – that he estimated the ***forces*** holding the planets in their orbits using ***Kepler’s third law*** and comparing the ***force*** holding the moon in its orbit with the ***force*** of gravity on the surface of the Earth. In 1666, however, Newton was just beginning the path to the ***concept of force*** that is now taught in schools [Westfall, 1971]. It is also doubtful that the physicist Newton, unlike the physicist Galileo, perceived Kepler’s astronomical laws as fundamental, and not as empirical, even if mysteriously elegant relationships, like Kepler’s 1596 “cosmographic” model of the Solar system.

The main factor in distrust of Newton’s testimony, apparently, was the bewilderment, namely how he *“compared the* ***force*** *requisite to keep the Moon in her Orb with the* ***force of gravity*** *at the surface of the earth”* in 1666.

This factor could be removed if the quoted phrase were edited: “…compared the ***motion*** of the Moon with the ***free fall*** of an apple thrown with a sufficiently high horizontal speed on the surface of the Earth”. This was quite possible, as shown in §2, by ***considering only circular orbits without the concept of force and without Kepler’s laws***.

It is also worth considering that the events of half a century ago were described by a person who knew that Kepler’s laws are mathematically equivalent to the law of universal gravitation. That is, that Newton wrote as a theoretical physicist in 1718, but not as a historian of physics in the distant future. The advice of a 20th-century theoretical physicist fits this situation:

> If you want to find out anything from the theoretical physicists about the methods they use, I advise you to stick closely to one principle: don't listen to their words, fix your attention on their deeds. To him who is a discoverer in this field, the products of his imagination appear so necessary and natural that he regards them, and would like to have them regarded by others, not as creations of thought but as given realities [Einstein, 1960, p. 271].

Historians would do well to look in Newton's manuscripts of the 1660s for the origins of the thought experiment captured in the 1685 manuscript published in 1728. The apple, of course, is hardly mentioned there. These were not diary entries, but sketches of scientific thoughts.

In addition to Newton's own testimony (quoted above), four testimonies of his interlocutors are known about his stories in old age about the insight of 1666, from which his path to the theory of gravity began [Herivel, 1965, p. 65]. Only two interlocutors of Newton, who were not involved in science, mentioned the "fateful" role of the apple. And the other two interlocutors, who were very much engaged in science, testified only to the insight itself.

The unscientific nature of the first evidence and the "unfoundedness" of the second one helped historians of mechanics to suspect in these stories the invention of the aged Newton.

The same testimonies, however, were accepted with trust in two biographies of Newton – in the most detailed one, written by the prominent historian of science R. Westfall, and in the "most scientific" one, written by the physicist and broad-minded historian S.I. Vavilov [Westfall, 1983, pp. 154–155; Vavilov, 1989, p. 104]:

> Westfall: "What then is one to make of the story of the apple? It is too well attested to be thrown out of court… Newton must have had something in mind when he compared the moon's centrifugal force with gravity, and there is every reason to believe that the fall of an apple gave rise to it."
>
> Vavilov: "The story is widely known that Newton's discovery of universal gravitation was caused by an unexpected fall of an apple from a tree in Woolstorp. This story, apparently, is reliable and is not a legend."

How can one understand that, unlike the historians of mechanics, the biographers took Newton at his word without offering any reconstructions of his train of thought involving an apple?

Historians of mechanics saw in Newton primarily the author of the texts leading to his Principia ("Mathematical Principles of Physics", in the language of today). Biographers, on the other hand, strive to understand the protagonist as a living person, the person as a whole. And it is easier for a biographer to recognize a certain fact as incomprehensible than to accept its explanation, which contradicts the "non-mathematical" properties of the protagonist's personality.

Biographers Vavilov and Westfall did not explain their trust in Newton's story about the apple. One might try to do this for them, basing on their books, which pay serious attention to the completely "non-mathematical" religiosity of Newton. Both biographers thus recognized Newton's religious worldview as an essential part of his self-consciousness, which was not easy for Vavilov in the country of "scientific socialism" and militant atheism.

Serious research into Newton's manuscripts in biblical studies began only in the last decades. It turned out that the volume of these manuscripts is much larger than that written by Newton on physics and mathematics, and that he was a devote biblical freethinker: he thought as freely in religion as in science, and was no less critical of church authorities than of scientific ones [Iliffe, 2016]. He rejected church dogmas that, to his mind, had no basis in the text of the Bible. His foremost biblically free thought was that the doctrine of the Trinity was unbiblical. And he took this so seriously that he was ready to leave science, if otherwise he had to acknowledge this dogma publicly.

The biblical basis for the Ten Commandments coming directly from God, however, is undeniable. And to think that Newton could neglect the commandment: "*You shall not bear false witness*" means to question the sincerity of his faith. Newton's biographers did not raise such a question, and therefore could not admit that Newton deliberately lied when talking about the apple. He could be mistaken in some of his judgments, but this is not at all like deliberately distorting the historical facts known to him for the sake of a selfish goal or for the sake of appeasing someone's priority claims, if he considered them unfounded. For the biblical theist, honesty is not just a matter of decency, but something of vital importance.

Even if the historian of science is an atheist believing that all religions are "relics of the dark past" and that in a dozen or a hundred years all of them will remain only in museums, while studying the life and work of a theistic physicist from the "dark past", the historians have to take into account this personality trait of a physicist, since it was so important to him. Newton's manuscripts, for example, show that even in the evolution of his views on the foundations of dynamics and the concept of force, in his opposition to Descartes' vortices his religious ideas played a significant role [Westfall, 1971].

As already mentioned, Einstein saw the role of *"religious instincts… in helping the reasoning faculty toward its highest achievements"*. Such achievements include, first of all, the invention of new fundamental concepts as *"free inventions of the human spirit (not logically derivable from what is empirically given)"*.

Before "mathematizing nature", Galileo, Newton and all other "magnificent" inventors had to invent new "invisible and illogical" fundamental physical concepts. Years and even decades elapsed between such an invention and the construction of a theory complete enough to become (together with the new concept) experientially verifiable and acceptable to the inventor's colleagues, if not immediately to all. It took Galileo and Newton about two decades to do this (Galileo from the 1590 manuscript to 1609, Newton from the 1666 apple to the publication of Principia, 1687).

The invention of new fundamental concepts is a key distinction of modern physics. In the construction of a *mathematized* theory, based on *invented physical concepts,* and in experimental verifications of the theory, intuition and creative efforts of a different kind, more constructive and logically consistent, are required. So, it is not surprising that Newton, in his old age, remembered the brightest moment of his apple clue that led him to the main invention of his scientific life and told his close ones about the falling apple, which happened to be fateful for his theory of gravity and general system of mechanics.

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