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The Rejection of Aether in Physics: On Writing History during Paradigm Shifts

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Abstract:

Eelco Runia's view of historical time is that the now and the past exert an alternating influence on each other. The most prominent expression of this is a dialogue between the historian and the historical actors in which the historian creates metonyms, replacement terms, for how historical actors are defined, which affects the description of the past. In this paper, Runia's conception of historical time has been tested through an empirical investigation into the changing descriptions of the process of rejecting the aether hypothesis, 1858-2022. After the process of phasing the aether out of physics had previously been explained as being caused by the gradual acceptance of the theory of relativity, the cause was suddenly superseded in the 1990s by the Michelson-Morley experiment conducted in the 1880s. During the 21st century, however, the aether once again returned as a concept. The reason for the changes, is the conclusion, could possibly be due to the ambition to give a rational picture of the development of natural science at every point in time.

Keywords:

Historical Time. Presentism. Philosophy of History.

Introduction

Explaining the reasons behind a changing world view is one of the great challenges for historians. When they reevaluate the past, there is a clear risk of controversy over whether they have either been lured into doing so by some contemporary fashion fad, or want to attract attention to some spectacular source. The changes in how the past is re-evaluated in historiography are particularly evident in the case of notable stages in the history of the natural sciences because they engage many historians and sometimes also a significant readership. Well-known examples of this are the evaluation of individual discoveries and experiments.

Thomas Kuhn notes that researchers in science often have been famous for results that they did not intend to achieve in their work, and conversely that important discoveries are seldom attributed to the real discoverers. One of his examples concerns the "discovery" of the planet Uranus.

In 1781, astronomer Frederick William Herschel described a celestial body that he had noticed recently and that moved slowly relative to the fixed stars (KUHN, 1962/1977, p. 175): "In the quartile near Zeta Tauri [...] is a curious either nebulous star or perhaps a comet." A few months later, Swedish astronomer Anders Johan Lexell claimed that the movement of the new celestial body could be best explained if its orbit was interpreted as revolving around the sun and thus that it was a new planet. The suggestion was very bold as everyone "knew" since time immemorial that apart from the earth there were precisely five planets. The question remains when Uranus can be said to have been discovered. Studies of old astronomical observations have indicated that a celestial body that may have been Uranus could have been observed on several occasions going as far back as 1690. Should the discovery of this planet then be attributed to these older astronomers, to Herschel who clearly determined its existence, or to Lexell, who suggested that the celestial body was a new planet? The history of the natural sciences abounds with similar examples, and Kuhn notes that it might therefore be impossible to attribute a certain discovery to an individual; discoveries are more often akin to a long process (KUHN, 1996, p. 115-116; KUHN, 1962/1977, p. 171-174), which results in the following conclusion in an article originally published in 1962: "In this sense discoveries have a proper internal history as well as prehistory and a posthistory" (KUHN, 1962/1977, p. 174).

To Kuhn's characterisation of the historiography of discoveries must be added Harry Collins' and Trevor Pinch's emphasis on the social context in which the discovery takes place: "The meaning of an experimental result does not [...] depend only upon the care with which it is designed and carried out, it depends upon what people are ready to believe in" (COLLINS; PINCH, 1998, p. 42).

The problem is exacerbated as well when posterity comes along and accuses historians of one thing or the other when they are no longer capable of defending themselves. It is true that this is partly what will happen in the following, but the purpose, and this should be emphasised, is not to rant over others' work but simply to demonstrate that writing history is not that easy, no matter how uncontroversial the subject seems to be from a contemporary vantage point. Before the empirical example which will illustrate this thesis is presented, the theoretical assumption which is intended to explain the results will be formulated.

Without wanting to obscure the nuances in the historiography of Kuhn, Collins and Pinch, it can still be said that it is characterised mainly by causal explanations pointing forward in time: Acceptance is preceded by reevaluation. However, the approach cannot explain all the changes that the past undergoes.

When Brazilian philosopher Hélio Rebello Cardoso Jr. categorises conceptions of time over the past 20 years in a 2021 article, it becomes clear that, while the differences between what he calls "presentist" and "anti-presentist" approaches may have decreased over time, there still remain disagreements among a number of identified "polytemporal" notions of "historical time" whether the past is always the starting point for causal explanations or if the direction of causality can also point *backwards* in time.

Can the past, then, be changed as a direct result of changes in the present (CARDOSO Jr., 2021, p. 158-159)? Cardoso Jr. responds by presenting Dutch historian (and more) Eelco Runia's view of historical time, earlier applied by him on analyses of memories of historical trauma (which sometimes also lead to a changed worldview). Runia's view of historical time is charachterised as the result of a dialogic relationship between now and then: "In short, a present event shall cause the past to engender new events from the old ones", says Cardoso Jr. in a line of reasoning which is summed up as follows: "It is not the discharged present from the weight of the past that can at last move on, but a future moved by a brand-new past" (CARDOSO Jr., 2021, p. 161-162).

In the cited 2008 article, Runia himself specifies his conception of time through an account of how historians use, construct, and deploy *metonyms*, figures of speech that function as replacement terms primarily for historical actors or groups of actors. These metonyms, chosen in dialogue between the historian and the historical actors, become key parts of the historiography to make it seem true or plausible, exemplified by the phrase "Bush invaded Iraq [in 2003]" (RUNIA, 2008, p. 20-23). In the present study, it has been investigated whether this view of history can explain a case of changed worldview, based on the assumption that even a *cause of a change* can be expressed with a metonym.

The empirical example concerns the hypothetical substance *aether*, the potential existence of which has been based on assumptions with roots in ancient Greek natural philosophy.[1] The word, which is also Greek in origin, means "air". "Aether" is not a synonym of the air that we breathe, however, but has had a much more complicated meaning throughout history, which is indicated by another synonym which is still used for its properties as a "fifth element", *quintessence*, used today to signify "the essential" or "the best of something". Assumptions about this substance have been used throughout history to explain complicated scientific and medical phenomena such as motion, light, heat, magnetism, electricity, and nerve impulses, but even a superficial survey of the various models of explanation for these phenomena demonstrates that aether has been associated with very different properties over time. The changing meaning of the word as described to the public can be easily read in popular science representations that have been published at different times.

In this article, I argue that Runia's view of history has a high explanatory value for interpreting the answer to the following question: How do scientific developments in a certain field of research influence the popular science representations of the truths of that field?

[1] Some authors cited in this article spell the word "ether" or "eter".

Perceptions of the fifth element

According to Edmund Whittaker (1951) and a number of contributors to an anthology edited by Geoffrey Cantor and M. J. S. Hodge (BUCHWALD, 1981; CANTOR; HODGE, 1981; SIEGEL, 1981; STEIN; 1981), the development of the views of aether up until the end of the 19th century can be summarised as follows.

The oldest descriptions of this substance go back at least to Ionian philosophy in the sixth century B.C. and Anaximenes of Miletus, who regarded aether (Greek *aither*) as a higher, finer type of air existing between the firmament and the air (Greek *aer*) that we breathe close to the surface of the earth. He contended that the soul of living beings consisted of aether, in this state called *pneuma*, which left the body at the moment of death to join the heavenly world aether, which also invested the concept with a theological significance. A similar view was held by Heraclitus (c. 540-480), who considered aether to be a superior form of fire, but otherwise associated the substance with similar properties as the ones alluded to by Anaximenes.

The first more elaborated theory of aether was presented by Aristotle (384-322) and represented in part a synthesis of contemporary knowledge. Apart from the four basic elements earth, fire, water, and air, Aristotle's cosmos also includes a fifth element - aether, in later times called *quinta essentia.* Aristotle's aether differs from the other four elements in several ways. While the latter can cease or begin to exist, change in terms of form and quality and be affected by temperature and humidity, aether can only be moved and otherwise not altered. The natural movements of the four elements are "up" or "down" in relation to the imagined spherical surface of the earth, while the natural movement of aether is to move parallel to it. The later medieval European physics was essentially going to be based on this world view. The quintessence was called pneuma when it was close to the surface of the earth and aether when it was above the atmosphere (CANTOR; HODGE, 1981, p. 2-11).

René Descartes (1596-1650) can be said to have initiated the more recent speculations about the concept of aether. During the epoch that started in his time and lasted until the 19th century, the researchers tried to explain not only *how* the universe worked, but also in a deeper sense *why* it worked like it did, which in a way contributed to the preservation of old connections between science and theology. The Cartesian world view is an example of this. His universe holds three element, consisting of different kinds of particles; fire, air, and earth, which together make up an infinite extent, where vacuum does not exist and where all movements of matter emanate from divine intervention. Fire and earth particles are by-products of the creation of air. The earth is surrounded by air, which is surrounded in turn by fire matter, which also partly fills the spaces between the air particles. Left-over fire matter has gathered in the "midst" of the universe and formed the sun. Movements in the light, whirling fire matter create heat, and when pressure waves of these whirls replicate in the air, we experience light. In other words, this Cartesian aether is constituted by air imbued with fire matter, where the energy of the particles replicates in the sea of particles in the same way that billiard balls collide on a pool table; the particles influence other particles only through relaying impact to particles in their immediate proximity. Later in the 17th century, Descartes' ideas were developed by Dutch astronomer and physicist Christiaan Huygens (1629-1695), who described light as a *wave motion* in the universal aether (CANTOR; HODGE, 1981, p. 11-14; BUCHWALD, 1981, p. 215-216).

Periodically throughout his career, Isaac Newton (1642-1727) also worked on formulations regarding the nature of aether. Newton's matter is constituted by particles of different sizes, which determine the firmness of a material. Hard materials consist of larger particles and soft materials consist of smaller particles. Movements in matter are dependent on a number of "active principles", for instance gravity, which can be compared to expressions of divine will. Matter cannot penetrate other matter, but large particles can be broken into smaller particles. Very fine air particles can be broken down to aether, which is constituted by the smallest particles of the universe. Aether particles repel other particles, including other aether particles. Aether can manifest in different forms, however, either as aether spirits or as a flexible matter with different degrees of density. The density between these particles increases in relation to the distance from the sun and in that way influences celestial bodies, which is why the orbits of planets move slightly helically in the direction of the sun. The substance is also the basis for phenomena such as light, heat, and muscular movements (in the form of nerve impulses). Experiments showing that heat spreads also in a vacuum made Newton assume that aether particles remain in a closed space even after air particles have been removed. Newton perceived light as a *flow of aether particles*. In contrast to Huygens, then, his aether does not affect other matter through waves in a sea of particles, but through direct flows of particles, sometimes called aether winds, in the same way as running water on the surface of the earth affects a turbine wheel in a hydropower plant. This description of the nature of light was then going to compete with Huygens' version until the early 20th century, when the two views were combined (CANTOR; HODGE, 1981, p. 20-24; BUCHWALD, 1981, p. 215-216).

From the middle of the 18th century, various aether hypotheses were formed in different areas of physics, depending on what scientific phenomenon individual researchers were trying to explain. Thus, people started discussing a light aether, an electric aether, or a magnetic aether. The hypothesis from this period that remains most well-known today is the calorie hypothesis of French chemist Antoine Lavoisiers (1743-1794), a further development of the older hypothesis concerning fire matter. He believed that calorie particles could penetrate other matter and thus heat it. If a large enough quantity of calories was added, this would make the matter melt or vaporise. In that case, each solid particle would have been completely enveloped by calories. Another aether hypothesis was formulated by American scientist Benjamin Franklin (1706-1790), who described electrical current as a flow of aether particles from areas with high concentrations of aether to areas with low concentrations. According to him, the same principle was behind the diffusion of heat. We can see that both Lavoisier's and Franklin's hypotheses adhere to the Newtonian tradition through their direct-acting flows of aether particles (CANTOR; HODGE, 1981, p. 27-30).

Over the first few decades of the 19th century, the different areas of physics would develop at a tremendous rate. The measuring instruments and knowledge of mathematics improved considerably, and in most cases the remaining connections to theology were severed. With the new tools, researchers continued to try to address the most mysterious scientific phenomena. French astronomer and mathematician Pierre Simon de Laplace (1749-1827) described a world where all matter, electricity, magnetism, heat, and light consist of different particles called molecules, a kind of "material points" with no measurable spatial extent, but mutually attracting each other.

The wave theories returned and replaced the theories of direct-acting aether winds. Later in the 19th century, the hypotheses of different forms of aether were gradually abandoned in favour of hypotheses of a universal "world aether", like in antiquity. However, in optics the problem of the nature of light remained. The general view towards the end of the 19th century was still that light was a wave motion in an aether, usually called light aether or world aether, and investigations were based on that assumption (CANTOR; HODGE, 1981, p. 49-50; BUCHWALD, 1981, p. 217-222, 225-230).

The Michelson-Morley Experiment

In their attempts to measure the velocity of the earth in relation to the sea of aether, a couple of American physicists performed a series of experiments, one of which became very famous. The purpose of Albert Abraham Michelson (1852-1931) and Edward Williams Morley (1838-1923) was to test if the aberration (that is, the observed difference between, for instance, the angle of starlight onto earth and the "real" position of stars in the firmament), apart from being an effect of the speed of light in relation to the velocity of the earth in its orbit around the sun, was *also* affected by the velocity of the earth in relation to the velocity of an assumed light aether. Did the earth move at such high speed in relation to the light aether that the position of stars in the sky seemed to shift for that reason as well?

An experiment conducted by Michelson in 1881 had more or less been a failure (COLLINS; PINCH, 1998, p. 27-55). According to the authors themselves in their article, a machine called an *interferometer* had been constructed and placed in a laboratory in Potsdam outside Berlin (MICHELSON; MORLEY, 1887). Simply put, a ray of light was sent across a plane surface and then split into two by means of a semi-reflective mirror, which reflected one half of the ray of light and allowed the other half to pass through the mirror. The two rays were directed perpendicular to each other, and then reunited in one spot through the use of mirrors. Through measuring the interference of the two rays of light (that is, the interaction of the light waves), their length in relation to each other could be determined with extreme precision. One ray was pointed in the direction of the earth moving around the sun, and the other one at right angles against it. The aberration then caused the latter ray to be somewhat displaced and created an angle between the two rays that was slightly larger than 90°, at the same time as the "displaced" ray was reflected in turn at an angle that was twice the size of the displacement between the two rays. The exact lengths of the rays of light were then calculated in the usual way through multiplying their imagined velocity with the time it took for them to travel the distance from the source of light to the instrument that measured the interference. In accordance with Newtonian mechanics, the speed of the ray of light moving in the direction of the earth was calculated as the speed of light added to the velocity of the earth in its orbit around the sun.

Through assuming that the velocity of the earth in relation to the imagined light aether should displace the perpendicular ray of light differently, partly depending on the time of day or night of the experiment, and partly depending on the exact position of the rays of light in relation to the direction of the earth moving around the sun, Michelson had hoped to be able to determine this relative velocity.

However, no influence whatsoever of any aether wind on the aberration of the ray of light could be demonstrated. The null result was later explained as due to unfavourable conditions for the experiment. Above all, the interferometer had been incredibly sensitive to vibrations, both vibrations from the ground and vibrations that occurred when the machine was rotated (MICHELSON; MORLEY, 1887, p. 450-453).

Six years later, Michelson repeated the experiment, this time with Morley and on American soil in Cleveland, Ohio. First, a very sophisticated interferometer was built. On top of a brick podium, a slab of stone one and a half metres across rested on a layer of mercury, which made rotation possible. A great many mirrors were attached to the flat surface of the stone slab, allowing the two rays of light to travel back and forth as far as eleven metres before the interference between them was measured. During three days in July, sixteen times in the morning and sixteen times in the evening, the interference between the rays of light was computed, at the same time as the slab of stone was rotated very slowly on the layer of mercury once per measurement period.

Once again, the researchers were unable to demonstrate any influence of aether wind on the aberration of the rays of light; the relationship between the two rays remained the same at all times (MICHELSON; MORLEY, 1887, p. 450-453). However, the precision of the experimental method made it famous, and many physicists later tried to explain Michelson's and Morley's null result.

One of them was Dutch physicist Hendrik Antoon Lorentz (1853-1928), who tried to recover the result of the experiment in the 1890s through an assumption that solid bodies (still based on the tenet in Newtonian physics about an absolute space) contract in such a way that when their velocity approaches that of light, their length in the direction of travel approaches zero. They are subject to so-called *length contraction.* (The Irish physicist FitzGerald had formulated similar ideas a few years earlier.) He claimed, therefore, that Michelson's and Morley's interferometer had contracted slightly in the direction of the movement of the earth, which entailed that the ray of light that travelled in this direction covered a somewhat shorter distance than had been calculated, and in that way "compensated" for the assumed increased aberration of the perpendicular ray due to the aether wind. As a consequence of the Michelson-Morley experiment, however, more and more researchers were getting used to the idea that a material aether with properties that could be determined through experiments might not exist.

Albert Einstein's (1879-1955) role in the history of aether is well known, but controversial among historians of science. A relatively large body of research has tried to map out what or who influenced him in his work, directly or indirectly. The issue has been the extent to which other researchers had prepared the ground for the theory of special relativity, published in 1905. Seminal contributions to this particular research have been offered by Whittaker (1953), Gerald Holton (1973, 1995), Arthur I. Miller (1982), and Peter Galison (2003), but also by Einstein himself in a straightforward popular science presentation of his two theories of relativity, originally published in 1916 (1916/1997).

Ever since early adolescence, Einstein had conducted thought experiments about the nature of light, among other things. During studies in Switzerland in the 1890s, he made contact with ongoing research in the area, including works by Lorentz, but did not feel convinced by the descriptions provided regarding light. In his own work, he instead developed an entirely new and revolutionary view, namely that the speed of light was in fact *constant* (simply put) and not dependent on the velocity of either the source of light or any reflecting mirrors. Gerald Holton (still going strong) has noted that Einstein, according to himself, had developed this idea so far *before* he learned about the Michelson-Morely experiment that he was not particularly suprised when he later found out about it, probably through Lorentz's research. The null result of the experiment had only confirmed something that he himself already saw as certain. He had already from the beginning seen the Lorentz-FitzGerald contraction as an ad hoc explanation (EINSTEIN, 1916/1997, p. 80-82, 150, 153; MILLER, 1982, p. 8; HOLTON, 1973, p. 282-286, 310-316, 322; HOLTON, 1995, p. 59-60, 193, 250).

The consequence of Einstein's interpretation of the properties of light, then, was that the ray of light that had travelled in the direction of the earth moving around the sun in the experiment had "only" moved at the speed of light (just like the perpendicular ray of light), not with the velocity of the earth added to the speed of light, as the previous research had assumed. The perpendicular ray of light in the interferometer had moreover not been affected by any aether wind whatsoever (regardless if aether existed or not), which consequently provided a natural explanation for the null result of the experiment.

Einstein's assumption about the speed of light would later constitute one of the cornerstones of his theory of special relativity, which describes the properties of space and time (for situations in which the forces of gravity can be neglected). The accuracy of Lorentz's assumed length contraction was in a certain sense confirmed. Michelson's and Morley's interferometer had in fact contracted in the direction of the movement of the earth, *but only for observers who had been motionless in relation to the sun* and seen the earth rush past. The two physicists had obviously been travelling in space in orbit around the sun with their interferometer, and had therefore not been able to register any length contraction in the machine (EINSTEIN, 1916/1997, 80-82, 151, 153; WHITTAKER, 1953, p. 38).

Already in the early 1950s, Edmund Taylor Whittaker, the mathematician and historian of science mentioned above, radically played down Einstein's role in the development of a transformed view of time and space. According to him, the theory of special relativity was to such a large extent based on previous research that it can only be described as a version of what Lorentz and others had already demonstrated (WHITTAKER, 1953, p. 40; GALISON, 2003, p. 353). Later in the 20th century, Holton would object to this description of the theory of relativity. His take is to highlight Einstein's individual intellectual achievement, at the same time as he denounces the kind of historiography that suggests that major scientific syntheses should be seen as the results of experiments. Using quotes from Einstein as support, he instead refers to thought experiments and sudden inspiration, or that the solution to a problem appears "indirectly" in an unexpected situation (HOLTON, 1973, p. 37-39, 263-264, 328). Soon after the turn of the 21st century, Peter Galison took a position in the middle between the actor perspective and the structural perspective in a substantial and empirically well-founded monograph about Einstein and French mathematician Henri Poincaré (1854-1912). On the one hand, Einstein's individual achievement is recognised in terms of the image that has been presented of him as a fearless rebel, understood in opposition to the careful reformer Poincaré, who was never able to abandon his belief in the existence of aether. On the other hand, Galison includes an in-depth argument about the influence of one of the most topical technical problems at the time which Einstein encountered in his work (from 1902) as a reviewer of patent applications at the Swiss patent office in Bern, namely the problem of synchronising clocks, carried out as an aspect of infrastructure development and in connection with the introduction of standard time (GALISON, 2003, p. 228-229, 232, 243-248, 297, 313).

Einstein emphasised later in life the significance of the Michelson-Morely experiment for making other physicists accept the theory of relativity, but the notions of the existence of aether, which were deeply entrenched after all, still considerably prolonged the reception history of the theory of relativity; the theory did not in fact disprove the existence of aether, since how can you prove that something does *not* exist? Even Einstein himself presupposed the presence of some kind of aether. For instance, in a presentation in 1920, he said (CANTOR; HODGE, 1981, p. 54): "To deny ether is ultimately to assume that empty space has no physical qualities whatever." What he rejected was precisely the material properties that had been associated with the concept in earlier periods. Despite this stance, the gradual acceptance of the theory of relativity in the research community resulted in a simultaneous wholesale rejection of the existence of aether. The aether that had filled the universe ever since the time of the ancient Greeks was now eliminated in the course of a few decades (HOLTON, 1973, p. 22; CANTOR; HODGE, 1981, p. 53-54; ELZINGA, 1997, p. 22).

Among professional physicists in Europe, the implementation of the theory of relativity was hindered and delayed in some places due to prevailing antisemitism between the wars since Einstein was of Jewish descent. In Sweden specifically, the implementation happened in the years after World War I without major problems, when empirical support for the theory was emerging. Einstein's 1921 Nobel Prize in Physics (bestowed in 1922) is an indication of this (WIDMALM, 1999, p. 244-245).

The rejection of aether in physics

To illustrate the significance of the actual development of events for the written history, this shift in the conception of aether will be traced through a number of translated quotes from Swedish encyclopedias published over a period of approximately 160 years, 1858-2022. The presentation is based on the assumption that these encyclopedias at any given point in time describe the generally prevalent notion of the concept of aether. The choice of text genre and the selection of texts within the genre do not claim to be representative of all perceptions of the aether that flourished during the relevant time period, but have been judged to constitute a sufficiently large selection of related sources to, overall, constitute a good approximation of how the substance was presented to the Swedish-speaking public during time period in question. On the whole, the encyclopedias are assumed to reflect the view of aether most widely accepted by the majority at any given point in time. The exposition results in an argument that part of the changed historiography that appears here can best be explained with the kind of causal explanations that Runia has previously described.

Consider the articles quoted below where the word aether is explained and note how these explanations change over time. Unless otherwise noted, each article is cited in its entirety. The first of the three oldest examples is from the first edition of the four-volume work *Konversations- och Universal-Lexikon*, the first volume of which was published in 1858:[2] "**Aether**. Phys.: This is what we call an invisible, fine, elastic substance, which must be imagined as a kind of higher air, extended throughout universal space. This assumption has been established mainly through a particularly careful inquiry into the phenomena of light" (ETHER, 1858, p. 69).

The first edition of *Nordisk familjebok*, 1881 (and the second edition, 1907):

> **Aether** (fr. Greek aithēr, air, the thinest, the finest). 1. Phys., a substance with an extraordinarily low density but with great elasticity, which permeates universal space and all matter. The presence of aether has not yet been possible to prove directly; it is only a hypothesis, upon which the accounts of manifestations of light, heat, and electricity nevertheless rest (FORSSMAN, 1881, p. 761; FORSSMAN, 1907, p. 975).

The second edition of *Fröléens Konversationslexikon*, 1914:

> **Aether** (Greek) is the term used in physics for an assumed "something", which emanates from bodies without itself being a bodily or tangible matter, but a wave-like movement in the hypothetical "light aether", which must be assumed to permeate the entire universe. Aether must be regarded as an infinitely fine, imponderable, exceedingly elastic medium, which penetrates all substances. Thus, the infinite universal space resembles a sea of aether, in which all natural processes take place. Without friction, the planets glide through the aether (ETER, 1914, p. 645).

In these examples, we can see that the existence of aether is presented as almost certainly established. The nature and expansion of the substance are described, as well as the important role that it plays in the universe. The only thing missing is that it "has not yet been possible to prove directly", but the reader is given the impression that it is only a matter of time

[2] In this and all the subsequent quotations from articles on aether, any passages on "diethyl ether", spelled the same way as "aether" in everyday Swedish, have been left out.

before researchers will be able to reach that goal. Still in the mid-1920s we can find a similar view of this mysterious substance, as the following two examples show:

The first edition of *Tidens Lexikon*, 1925: "**Aether**, phys., an imponderable substance with extraordinary elasticity which is assumed to fill both universal space ("empty space") and all matter. This assumption has been made in order to make it possible to explain the movement of light as a wave motion also through empty space. Cf Light (ETERN, 1925, p. 661).

The Swedish Academy's *Ordbok öfver svenska språket* was completed and published volume by volume in alphabetical order 1893-2023. Still in the 1920s, work was going on with words starting with "A". "Aether" was first printed in 1922 and was published in a volume three years later:

> **AETHER** (- - -)
>
> II. science (phys. & astr.) the term for various hypothetical extremely fine, light, and elastic substances; esp. according to some scientists a term for a substance assumed to permeate all bodies, fill universal space, and serve as a medium of light, according to others a term for a substance assumed to be the reason why starlight wanes and why the orbits and orbital speeds of comets and other celestial bodies decline. (- - -) cf LIGHT-, WORLD AETHER (ETER, 1922/1925, p. 751).

The definition of aether in the seventh volume of this dictionary does not in principle deviate from *Konversations- och Universallexikon* from 1858. It is true that the hypothetical nature of the substance is mentioned, and a couple of different views of its function are reported, as well as the assumption regarding a number of different types of aethers, but the very existence of aether is not seriously questioned. The first out of the two references in the article is explained as follows 15 years later, in 1942 (the article originally printed the year before): "**LIGHT** (- - -) **– AETHER** science [...] The hypothesis of a light-aether, a substance in which light waves propagate, and which is present everywhere in between bodies. (- - -)" (LJUS-ETER, 1941/1942, p. 977).

Towards the end of the 1920s, however, a slightly more cautious view of the substance figures in some Swedish encyclopedias. In the third edition of *Nordisk familjebok* from 1927, there is a new author behind the article, which indicates that the position of aether in physics has now started to falter:

> **Aether**. 1. (Phys.) A (hypothetical) weightless, elastic substance, which (according to the aether hypothesis) is supposed to fill universal space and permeate matter, transmitter of light waves (heat radiation, radio waves, etc.). The concept is present already in Aristotle, further in Giordano Bruno, Descartes, and others. The most common view of aether derives from Huygens, and on this ground researchers like Faraday and Maxwell based their work. The question if aether rested in space or was carried by matter when in motion gave rise to some remarkable experiments, which in turn caused the formulation of the theory of relativity (see this term), which completely rejects the presence of any aether (TANDBERG, 1927, p. 1101-1102).

It is now emphasised that aether is a hypothesis and the presentation here resembles a history of science survey which concludes with the formulation of Einstein's theory of relativity which, according to the author who does not really take a personal stand regarding the problem, "rejects the presence of any aether". A similar but still somewhat more sceptical approach to aether can be found a few years later in the first edition of *Svensk Uppslagsbok* from 1931:

> **Aether** (originally from Greek aithe'r). 1) Phys., hypothetical substance, assumed to fill all empty spaces and permeate all matter. Aether was introduced to physics by Huygens as a transmitter of the mechanical-elastic oscillations by which he sought to explain the radiation of light and heat from celestial bodies. Some researchers, among them Swedish physicist Edlund, tried to explain the properties of the electrical field through positing a particular electrical aether alongside the light aether. However, the superfluity of that assumption was demonstrated by Maxwell, whose electromagnetic theory of light defined light as an electromagnetic field extending through the light aether. During the latter half of the 19th century, there were intense debates about the nature and properties of aether. Although this controversy cannot be said to have had a positive result, it is significant mainly as background for Einstein's theory of relativity. The trend nowadays seems to be to reject the theory of aether as unnecessary. In the worldview that has been established on the foundation of the theory of relativity (see this term), there is no room for aether. – Cf E l e m e n t 2)
>
> (- - -) (LEIDE, 1931/1938, p. 957).

In this case as well, the emphasis of the presentation is on the development of the concept of aether over the past few centuries, but "nowadays", that is in 1931, aether is no longer thought to exist. An alternative interpretation of the article is that the question whether or not aether exists is no longer seen as particularly interesting or relevant, since the theory of relativity is now becoming more generally accepted. This is also confirmed in *Allas Uppslagsbok*, published ten years later, in 1941:

> **Aether** (Greek). 1. A substance, earlier assumed to fill universal space, the sea of aether, in which all natural processes take place and due to which the influence of gravity between celestial bodies could be explained. Through Einstein's general theory of relativity, the idea of aether is abandoned, and movements in space are explained by means of the mathematical properties of spacetime (ETER, 1941, p. 192).

Yet, the fact that the lexicographers found themselves in a transitional period is demonstrated on the one hand by the definition of the word in *Uppslagsbok för alla* (ETERN, 1939, p. 161), "**Aether**, universal space; the imponderable substance which has been assumed to fill it", and on the other hand by the fact that the article in the second edition of *Svensk uppslagsbok* from 1956 was kept almost unchanged compared to the version in the first edition (LEIDE, 1956, p. 1059).

At least by the end of the 1950s, however, the Swedish encyclopedias had entered a new era, which conclusively declared the aether hypothesis dead. The first example is from the first edition of *Focus: Uppslagsbok*, published in 1958: "**Aether**, e.g. 'air', — 1. In older physics, a weightless substance which was supposed to fill space. Following the theory of relativity, the hypotheses about aether have been abandoned" (ETER, 1958, p. 524)

The first edition of *Bonniers Lexikon* went even further in 1964:

> **Aether** (from Greek aithe'r, air). 1. Orig. a term for a hypothetical substance with very particular properties deviating from those of other known substances, in which the propagation of light was assumed to take place. Nowadays, no material properties are associated with the concept of aether, and it is used only as an expression for the characteristics of matter and empty space that enable the propagation of light. Cf Theory of relativity (ETER, 1964, p. 675).

In this case, the subject has been completely excluded from contemporary physics, and the word only survives at this time as an expression in language. The view of aether as a form of matter is regarded as altogether a thing of the past. This description would also stay the same in all the examined encyclopedias over the next 25 years. Two examples from the pile of many small and medium-sized encyclopedias that were published in this period are the first edition of *Bra böckers lexikon* (ETERN, 1976, p. 118), **"aether**, a hypothetical substance that was assumed in the past to fill empty space in the universe", and the second edition of *Bonniers lilla uppslagsbok* from the same year:"**aether**, the weightless 'substance' in which matter floats, according to old ideas in physics" (ETER, 1976, p. 92).

This could have been the end of this history, since the reception process of the theory of relativity had been completed among physicists and the general public, and aether could have continued to be presented in similar ways in all encyclopedias published from then on. However, in the 1990s something very remarkable happened, and it happened in the largest Swedish encyclopedia for several decades, namely *Nationalencyklopedin.* The ambition for the articles, stated explicitly in the foreword, is for "the historical perspective [...] to provide a background for contemporary issues" and in this manner "mirror our time" (PROGRAM och perspektiv, 1989, s.p.). For aether, this entails one of the most voluminous articles on the subject thus far, published in the fifth volume in 1991 (later republished in *Nationalencyklopedin Multimedia 2000* in 2000, and in *Nationalencyklopedin* on the Internet):

> **aether** (originally from Greek aithē´r 'the superior, cleaner air') (---)
>
> **2** an invisible, elastic substance that was earlier believed to fill universal space and all empty spaces in matter. The concept was introduced in physics by Huygens, who contended that light is a wave motion in the aether. Maxwell's studies of electromagnetic phenomena seemed to corroborate this. During the latter part of the 19th century, several attempts were made to prove the existence of aether. However, famous experiments by A.A. Michelson and E.W. Morley finally established in 1881 that there is no aether. As a result of Einstein's theory of relativity, the concept of aether was proven superfluous, and it is not used in modern physics. Nowadays, the term is used figuratively about the imagined medium through which radio waves are transmitted (cf ►etermedier). (MESSETER, 1991, p. 625; MESSETER, 2000, s.p.; NATIONALENCYKLOPEDIN, 2022, s.p.)

The article is of course a history of science overview like the articles about aether over the previous 30-40 years, but the slow exit of the substance from physics, which we have seen did not reach completion until the 1950s, has mysteriously disappeared. The reader is now given the impression that this process took place already in the 19th century, when Michelson and Morley "finally established in 1881 that there is no aether" and Einstein turned the entire concept of aether "superfluous".

A similar position can be found in the second edition of *Bonniers Lexikon*, published three years later, which shows that the notion of aether presented in *Nationalencyklopedin* was not an isolated case.

> **aether** [from Greek aither, air]. 1. An extraordinarily fine and imperceptible substance which was believed to fill the entire universe in older physics. Light and radio waves were assumed to propagate as oscillations in the aether ("aether waves"), like sound waves in air. But above all, aether was the material carrier of absolute space, the frame of reference that was common to all positions and movements. However, the famous Michelson-Morley experiment in 1887 demonstrated that the speed of light was the same in all directions, even though the earth supposedly travelled through the sea of aether. This discovery caused a crisis in physics. It was solved by → Einstein and the theory of relativity, which turned aether superfluous (ETER, 1994, p. 213-214).

While the experiment conducted by Michelson and Morley has been dated correctly here, in the year 1887, and it is no longer defined as the end of the aether hypothesis but rather as the beginning of the end, this end is described as definite due to Einstein's "solution" to the problem through his theory of relativity, the first version of which was published in 1905. The difference between this version and the presentation in *Nationalencyklopedin* is certainly not insignificant, but it is still not apparent in any way here that the attitudes of physicists regarding the existence of aether remained ambivalent for decades and that it was still spoken of in the 1950s as a conceivable hypothesis.

The final example is from the Swedish-language division of the web-based encyclopedia *Wikipedia*, where articles are created and edited freely by the users themselves and monitored by moderators. The editing history of each article can be traced under the tab "View history". At the time of writing, this history shows that the article "Aether (physics)" has been edited continuously since it was created in 2003 until July, 2021. At that point, it comprised almost 900 words, and the most relevant parts in this context read as follows:

> **Aether** is an obsolete concept in physics. [...] Aether was believed to be an invisible, ephemeral substance that filled every corner of the universe. There have been different alternative views of aether, and the concept of aether has a long history as a hypothesis in physics and philosophy. (---)
>
> Towards the end of the 19th century, however, the ideas of a light-transmitting aether became dominant in mainstream physics. Aether was seen as a medium that enabled the movement of light. The idea of

> a light-transmitting aether was put to death by the Michelson-Morley experiment, which was unable to demonstrate the existence of an aether wind that was assumed to affect the movement of light. If light had moved in relation to a motionless light-transmitting aether, the velocity would have varied depending on the direction of movement of the machine and how the earth travels through the solar system at high speed.
>
> The theory of special relativity by Einstein got rid of aether in 1905. After introducing the theory of general relativity in 1916, he started hesitating. In a speech at the University of Leiden in 1920, he picked up on this topic and said that the theory of relativity according to him was entirely dependent on some kind of aether, only not the classical light-transmitting aether (---).
>
> Towards the end of his life, Einstein seems to have been convinced that "space-time" is a new form of aether, which somehow serves as a frame of reference for the property of inertia. Still today, it is unclear how inertia originates, and this foundational aspect awaits a solution. What was seen as a cosmological frame of reference under the label "aether" before 1905 - a kind of undefined "plenum" in absolute stillness, a carrier of light and the elektromagnetic field - is perhaps not entirely dead anymore.
>
> Even though an absolute majority of physicists today reject aether-based hypotheses, a background for "relativistic" effects is inuitively attractive to some. Several new concepts with aether-like properties have been proposed lately.
>
> Different theories of gravity have been suggested as alternatives to or extensions of the theory of general relativity, resulting in a privileged frame of reference which in some ways bears a resemblance to an aether quality. Furthermore, there are theories of quantum gravity, for example loop quantum gravity, which opt for this type of privileged frame of reference. (WIKIPEDIA, 2022)

In this final text, then, aether is not "as dead" as it has been over the past few decades, even though the Michelson-Morley experiment still put the old aether hypothesis "to death" and the theory of special relativity then "got rid of" it. The difference compared to the older articles is that it was now Einstein himself who started to resuscitate aether, after which other researchers have "lately" followed in his footsteps in this regard. The outline of scientific development is thus presented as quite rational in this final version as well.

In March 2022, the search terms "Einstein-aether theory" entered into the search engine OneSearch at Karlstad University, with 13 suppliers of data, yielded 365 hits in peer-reviewed academic journals published from 2005 and onwards (EBSCO Connect, 2022). I can honestly say that I do not understand everything that has been written about "Einstein-aether", apart from the fact that it plays a role as an empty but privileged coordinate system. It is in any case clear that the authors have always been in agreement with Einstein.

Discussion

There is a very large body of research dealing with the background and significance of outstanding achievements. Probably one of the most renowned researchers in this area is Thomas S. Kuhn. The change outlined above illustrates very clearly the type of paradigm shift described and analysed in his research, for instance in *The Structure of Scientific Revolutions*, the third edition of which was published posthumously in 1996. The concept of *paradigm* had (at least) two meanings for Kuhn. On the one hand, it could signify an "entire constellation of beliefs, values, techniques, and so on shared by the members of a given community", and, on the other, "the concrete puzzle-solutions which, employed as models or examples, can replace explicit rules as a basis for the solution of the remaining puzzles of normal science" (KUHN, 1996, p. 175). The stepwise rejection of aether among professional physicists and their historiographers might be an example of a paradigm shift in relation to the latter kind of paradigm, at least formally, but if this rejection is seen as a symptom of Einstein's theory of relativity being accepted by more and more people, the same paradigm shift can *also* pertain to the former type of paradigm in the sense that the world of thought that the scientific research community accommodated went through a radical change. However, it is not the paradigm shift itself that is investigated here, but the historiography of it. In this area too, there is some support to be had from Kuhn. The following is his advice for how historians of science should handle historical actors (from an article originally published in 1968):

> Dealing with innovators, the historian should try to think as they did. (- - -) [T]he historian should ask what his subject thought he had discovered and what he took the basis of that discovery to be. And in this process of reconstruction the historian should pay particular attention to his subject's apparent errors, not for their own sake but because they reveal for more of the mind at work than do passages in which result or an argument that modern science still retains (KUHN, 1968/1977, p. 110).

When this theory is applied to Michelson and Morley, a perspective emerges that supports the conception of time described initially. Considering the conclusions that they *themselves* drew from the experiment that was later to be so famous, we can see that they in 1887 found themselves in a situation similar to Frederick William Herschel's, 100 years earlier: They had discovered something important but they themselves did not understand it. In fact, in their study cited above, Michelson and Morley do not question the existence of light aether in any way, despite the null result. The conclusion that they draw from the experiment is simply that the relative velocity of the earth and light aether is quite certainly less than a quarter of the velocity of the earth orbiting the sun, but also that it is probably less than a sixth! Then, their presentation turns to speculation regarding how this sought-after velocity could *instead* be determined with accuracy. Perhaps the entire solar system was moving at such a rate at the time of the experiment that this movement, in combination with the earth moving around the sun, made the velocity of the earth in relation to aether close to zero? Or perhaps the aether does not at all move as closely to the surface of the earth as their own location while they conducted the experiment. Perhaps aether winds can be measured at higher elevations? Could the experiment be repeated on the summit of a mountain, with the interferometer protected by a glass structure? And if aether winds cannot be measured close to the surface of the earth at all, would it not be a better idea to perform more precise measurements of the aberration of Jupiter's moons, which had been studied before? This, then, was what seemed to occupy Michelson's and Morley's thoughts when their results were submitted for publication. As a matter of fact, according to Holton, both researchers were so deeply disappointed by the result that they abandoned any future plans of trying to prove the existence of aether. Michelson was awarded the Nobel Prize in Physics in 1907, partly due to his construction of the interferometer, but still towards the end of the 1920s he saw the aether wind as an unsolved mystery, despite the fact that other physicists had repeated the experiment earlier in the decade, precisely in a glass structure and precisely on the summit of a mountain, and arrived at the same null result. This means that neither he nor Einstein regarded the Michelson-Morley experiment as groundbreaking (MICHELSON; MORLEY, 1887 p. 458-463; COLLINS; PINCH, 1998 p. 39; HOLTON, 1973 p. 266-267, 284).

After referring to Holton's claim that major scientific theories rarely can be seen as emanating from single experiments, philosopher of science Imre Lakatos expresses a similar view in a published lecture that he gave in 1973:

> You can read that Michelson-Morley refuted the ether theory (---). If you have a look at contemporary periodicals, you find out that the 'refuted' theor[y] survived and were very lively for decades after, and that the real crucial experiment was actually invented at least forty years later. The big historical mythmaking is alive and well (LAKATOS; FEYERABEND, 1973/1999, p. 99).

Collins and Pinch are also on the same track (COLLINS; PINCH, 1998, p. 42): "The null results [of Michelson and Morley] passed from anomaly to 'findings' as the theory [of relativity] gained adherents." Thus, the fact that a scientific experiment can be established as significant by the research field in question only long after its execution has been known for a long time.

This study shows that the popular science view of the aether hypothesis at any given point in time stays very close to the generally accepted view in the field of science. This is of course only to be expected. A more remarkable finding is that the historiography of the gradual rejection of the aether hypothesis changed very suddenly in the early 1990s. When the historiographers in *Nationalencyklopedin*, *Bonniers Lexikon* and *Wikipedia* look back at the Michelson-Morley experiment, they see an experiment that proves to the entire world that aether does not exist, but when the historiographer in *Svensk uppslagsbok* looks back at the same experiment in 1931, he is not sure what it is that he really sees. The historiographer in *Fröléens lexikon* in 1914 does not see any experiment at all being carried out in 1887, at least not an experiment that he considers worth mentioning to the readers. Thus, the development of the popular science descriptions of the aether's existence changed over a hundred years from "probable" to "possible" to "unlikely", finally reducing the aether to a metaphor for "emptiness". However, a few decades later, the substance's gradual phasing out was replaced by a description in which the substance's existence was disproved in experiments as early as the 1880s.

The three latter encyclopedias have dated the rejection of the hypothesis not at the point in time when the majority of the research community had abandoned it, but instead already in the period when it is possible in hindsight to say that the process towards leaving the hypothesis behind began. These historiographers give the development towards complete rejection of the aether hypothesis a determinist interpretation of a presentist description of the order of events, which would have been seen as completely foreign by a majority of physicians in the world active in the decades around the turn of the century 1900, as well as historiographers and editors of other encyclopedias who were active as late as the 1950s. A bit more than 100 years after the Michelson-Morely experiment, the conviction that aether does not exist had grown so strong that the public was "ready to believe in" (COLLINS; PINCH, 1998, p. 42) the view that the experiment had immediately imparted this insight to the entire world. This interpretation now risks being understood as a truism by the readers of the encyclopedias, who will remain oblivious to the protracted death throes of the aether hypothesis.

The change that took place before 1991 can be satisfactorily explained theoretically with a view of historical time that emphasises causal explanations pointing forward in time: A growing acceptance of the theory of relativity leads to increasingly skeptical descriptions of the aether's existence and, in turn, to a growing belief in Michaelson and Morley's null results. However, such causal explanations cannot explain the changing historiography of the 1990s, where this whole reception process of has been excluded, which brings us back to Eelco Runia's conception of historical time, as summarised by Cardoso Jr. (CARDOSO Jr., 2021, p. 161-162): "In short, a present event shall cause the past to engender new events from the old ones."

There is no indication that the historiography in the three most recently published encyclopedias can be explained by new information becoming known about the Michelson-Morley experiment or about the reception process of relativity theory. In any case, it is not something that the article authors claim to know. The metonym which in earlier historiography was given as the main reason for the abandonment of the aether hypothesis, has now, without having been added new information about the past, been replaced by a new metonym, the Michelson-Morley experiment. The reason for this can only be speculated in this context. Does the shift express an ambition to attribute an early maturity to the subject of physics? Did it bother the authors that the world view of modern physics contained ancient ideas well into the 20th century? The otherwise qualified content of the articles speaks strongly against the fact that the slow phasing out of the aether hypothesis during the 20th Century would have simply been forgotten. Regardless, the past was changed by something that can best be described by a causal explanation pointing backwards in time, thus providing empirical support for the view of historical time described by Eelco Runia and as Cardoso Jr. later have characterised it: The reason for an event can be placed in the future as well as in the past (RUNIA, 2008, p. 20-23; CARDOSO Jr., 2021, p. 158-159).

We have learned from this example that it is not always easy to write history, and also that the results of historical investigations, just like studies in modern physics, ultimately depend on where researchers find themselves in Einstein's spacetime.

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