<AT>Mach’s Denial of Absolute Time

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<AB1HD>Abstract

<ABTXT>Mach repudiated Newton’s argument for absolute time. He denied there is such a thing as time itself that exists independently of any external change. In doing so, Mach failed to appreciate Newton’s scientific practice. Absolute time is intrinsically related to Newton’s laws of motion and the method of fluxions. Commentators have noted similarities between Mach’s rejection of Newtonian time and his rejection of the independent existence of atoms. In this article, it shall be argued that the juxtaposition of absolute time and the atomic theory is unsound. Mach had good reasons to question the existence of substantial time, and he went on to provide an alternative, ontologically relational account. Whereas his dismissal of atoms can be seen as a questionable form of “phenomenalism” or “positivism,” this is not the case regarding his position on time.

Keywords: Newton; Mach; history of philosophy of physics; philosophy of time

<T1HD>1. Introduction

Mach is well-known for paving the way for Einstein’s theories of relativity and for being highly critical of Boltzmann’s atomism (Stadler 2019, v). In abjuring the substantial existence of time and atoms, he applied arguments that could be categorized as “positivist” or “phenomenalist.” Neither positivism nor phenomenalism are generally accepted anymore. We might think Mach’s arguments challenging the substantivalist account of time or the independent atomic structure are not well-founded either.

This article makes the case that the two forms of criticism--the denial of absolute time, and the denial of an independent microscopic realm--should be evaluated differently. To that end, the following structure is applied. The second section analyzes Newton's concept of absolute time and its foundation in his empirical-mathematical physics. The third section focuses on Mach's harsh criticism of Newton. The fourth section considers the analogy between the criticism of substantial time and atoms. The fifth section concludes that although there are similarities between the two, temporal and microscopic physical phenomena are different. Accordingly, Mach's questionable denial of atoms should not be assimilated to his cogent reasons to abjure substantival time.

<T1HD>2. Absolute-Uniform Flow and tts Basis in Newton's Empirical-Mathematical Physics

<TXT>In the Scholium to the Definitions of his Principia, Newton characterizes absolute time as follows: "Absolute, true, and mathematical time, in and of itself and of its own nature, without reference to anything external, flows uniformly and by another name is called duration." Time is absolute as its existence does not depend on anything else but itself (excluding God's existence). Absolute time is distinct both from bodies and from the absolute space. It flows equally independently of any material change. The motions of bodies do not affect its pace in any way: "All motions can be accelerated and retarded, but the flow of absolute time cannot be changed," writes Newton. Time is external to bodies and their states of motion. The motion of a body is indifferent to duration and persistence.

Time has a metric structure because of its uniform pace. We do not observe such perfect uniformity, and we cannot measure it with any timekeepers. But we can mathematically grasp the difference between equal and unequal temporal intervals. Thus, Newton's argument for absolute time relates to his laws of motion. Forces are real causes of changes of motion. In the formulation of Eric Schliesser (2013, 89),[a]

Newton infers forces, which he treats as such 'true causes and effects,' from the measurement(s) of accelerations. This (theory-mediated) measurement(s) as well as the laws of motion on which it is predicated presupposes a conception of time.

When a body is not subjected to a net force, it moves equal distances in absolutely equal times. If there is a constant net force applied to a body, it moves equal distances in absolutely uneven temporal intervals (DiSalle 2006, 20–1). In Tim Maudlin's (2012, 5–11) reading, absolute Euclidian space is of the utmost importance for understanding Newton on time. Absolute rest is defined when a body occupies the exact same points of absolute space over any lapse of time. Likewise, in case of absolutely uniform or non-uniform motion, absolute space is needed to define how much time a body needs for traversing any amount of distance. There is no way of observing or measuring completely equal or unequal times, but we can mathematically comprehend them.

To see how absolute and uniform time is connected to Newton's calculus, it is useful to begin by considering the second law in the Axioms of the first book of the Principia: "A change in motion is proportional to the motive force impressed and takes place along the straight line in which that force is impressed." Force produces a change in momentum. Here the force denotes an instantaneous impulse, not a continually acting force. Newton explicates: a force will produce a motion, twice the force will produce double that motion, and thrice the force will produce triple the motion, and so on. Later, in proposition 24 of the second book of the Principia, Newton presents his law in a form recognizable to a contemporary reader: "the velocity that a given force can generate in a given time in a given quantity of matter is as the force and the time directly and the matter inversely."

[a] Is there supposed to be a block quote here? Either way, it can be within the paragraph or separated to a different paragraph.

I. Bernard Cohen (1999, 116) notes that Newton's intuitive application of limit-process makes "a transition from primary impulses to secondary forces that act continually." We can see this in the early stage[1] of his argument for the law of universal gravitation in the Principia. Newton refers to Kepler's area law. The law states that orbiting bodies sweep equal areas in equal amounts of time. The astronomical evidence for the law comes from the orbits of Jupiter's Moons. Newton uses the diagram below to illustrate his proof.

<Insert Figure 1 about here>

A body moves from A to B by the force of inertia. At point B it is impressed by an impulsive force. Accordingly, it won't continue its motion to point c but it will transfer to point C. Likewise, the body won't move to point d but to point D as an impulsive force is exerted on the body at C. Assuming a constant centripetal force toward S, the body's motion will be a curve from A to F: "thus the centripetal force by which the body is continually drawn back from the tangent of this curve will act uninterruptedly" (Principia, Book 1, Proposition 1). In his method, Newton begins with a sequence of instant impulses that produce a polygonal path. He ends up to the limit in which the sides of the polygonal will be indefinitely diminished. The chain of instantaneous forces becomes a constant force at a given time (Cohen 1999, 116). The triangles SAB, SBC, SCD, SDE, and SEF are all equal, as is maintained by Kepler's area law and is consistent with the collected astronomical data.

Newton's fluxions and the notion of the flow of time are essentially connected. Mathematical time flows uniformly and continuously. The "particles" of time are constant: hence the flow is uniform.[2] Cohen (1999, 117) adds that it is "more accurate to say that Newtonian time is the measure of the flux that can be divided into infinitesimals of equal 'length,' rather than to insist that Newtonian time is itself made up of some sort of discrete infinitesimal units." Newton himself writes in De Quadratura that fluxions are roughly "the

Augments of the Fluents generated in equal but very small Particles of Time" (qtd. from Cohen 1999, 117).

Fluents or flowing quantities presuppose the flux of time. A quantity continually increases or diminishes in time. It must be that time itself continuously accretes (Arthur 1995, 334). In his Method of Fluxions, under the subtitle "Transition to the Method of Fluxions," Newton seems to be using the notion of time in a rather cautious way.[3] Newton does not however treat time merely as a mathematical abstraction. In an unpublished manuscript from the early 1690's (translated by McGuire 1978), he describes time (and space) as self-existing entities which "in themselves do not fall under the senses." It is a mistake to take the "measures of time to be the things measured, for example days, months, and years to be times." Perhaps most clearly Newton claims that

> the Duration of a thing is not its flow, or any change, but permanence and immutability in flowing time. All things endure in so far as they remain the same any time. **<The duration of each thing flows, but>** its **<enduring>** substance does not flow, and is not changed with respect to before and after, but always remains the same (qtd. from McGuire 1978, 117).

There is an immaterial, unobservable time itself which flows at a steady pace. Bodies endure in a body-independent three-dimensional space. Temporal flow is completely external to the existence of space and the bodies that occupy places in that space. Time itself flows equally independently of whatever changes things undergo.

Interpreting absolute time in the ontological sense is not the only option. Schliesser reads absolute time as denoting a regulative ideal for the sake of Newton's physics.[4] Under this rendition, absolute time is approximated by our clocks and corrected by the astronomical equation of time. "In astronomy," Newton writes in the Definitions to the Scholium, "absolute time is distinguished from relative time by the equation of common time." Natural days are commonly thought to be equal although they are actually unequal. Newton remarks that “astronomers correct this inequality in order to measure celestial motions on the basis of a truer time.” Schliesser (2013, 90) takes Newton to be assimilating absolute time to mathematical time as the equation of time is both absolute and mathematical. The equation of time is a theoretical construct, and the corrected time is dependent upon sensory and mechanical measures, which are subject to improvement. Absolute time, under Schliesser’s reading, is not an entity or structure that can stand of its own. It is rather a regulative ideal that is needed to improve temporal measurement practices.

Schliesser thinks Newton has something like a temporal frame of the solar system in mind. The textual evidence comes from System of the World (Newton 1740, 58): “That the Planets, in respect of the fixed Stars, are revolved by equable motions about their proper axes. And that (perhaps) those motions are the most fit for the equation of time.” The temporal frame incorporating the equation of time is the finest approximation of absolute time. “So,” Schliesser (2013: 91) clarifies, “absolute (mathematical) time governs the shared temporal frame in the solar system (and nearby objects such as comets, etc.); it is what’s presupposed in one’s physics.” This does not imply that a moment of time extends across local frames. Instead, absolute time is a regulative ideal that motivates us to better our time-keeping measures. By contrast, true time is spread throughout space.

Newton’s metaphysics of time is imbued with theology. The Newtonian challenge is this: How do time and space follow from God without God being temporal or spatial? God should be in time and in space but not subject to change or divisible into infinity (Schliesser 2013: 95). This illuminates why time itself is also universal. Any moment is spread out over any place. As Newton has it in his De Gravitatione (quoted from Janiak 2004, 26): “The moment of duration is the same at Rome and at London, on the earth and on the stars, and throughout all the heavens.” Simultaneity is absolute, and so the present moment is universal:

"For we do not ascribe various durations to the different parts of space, but say that all endure simultaneously." This reasoning is evidently connected to Newton's omnipresence theology. In the General Scholium to the Principia he maintains God is always and everywhere. Newton's God "endures always and is present everywhere, and by existing always and everywhere he constitutes duration and space." Importantly for time's universality, as "each and every particle of space is always, and each and every indivisible moment of duration everywhere," God must be always somewhere (he could not be never or nowhere).

If absolute time is an ideal of measure, it is a human-made theoretical construct. It is difficult to square this idea with Newton's references to the flow of time, which, together with the evidence provided earlier, indicates an ontological position concerning the self-existing structure of time. To use established vocabulary, Newton is typically identified as a substantivalist rather than a relationist. Concerning time, a "Leibnizian relationist," as Michael Friedman (1983, 63) calls it, thinks there "can be primitive relations of distance, simultaneity, or temporal precedence between actual physical events, but such relations never hold between unoccupied space-time points." Here we can see a clear contrast to Newton's substantivalism. Absolute time provides an objective temporal order because simultaneity and succession are grounded in time itself. It is an observer-independent matter whether two events happen simultaneously or not (Earman 1989, 8–9).

We may image absolute time as a vector. The flow from past to future separates earlier and later moments. The front edge of the vector denotes the present moment. If two events are stacked vertically, their temporal difference is zero with regard to the flow of time, so they are absolutely simultaneous. If they are lined up horizontally, an earlier moment happens absolutely before the posterior, and the latter absolutely after the prior. Successive events are separated by a definite, non-zero temporal interval.

<T1HD>3. Mach against Absolute Time

<TXT>The purpose of The Science of Mechanics [SM], in Mach's (SM, vii) own words, is to

<L>□ "Clear up ideas."

□ "Expose the real significance of the matter."

□ "Get rid of metaphysical obscurities."

<TXT>He says that his primary motivation was not to write a book on the application of mechanical principles. SM is not written in heavily mathematical language. All the bullet points above concern his assessment of Newton's achievements in mechanics. Mach thinks since Newton no new principles have been stated in mechanics (SM 187). For this article, the most important section in SM is "Newton's views of time, space, and motion." Mach begins that section by quoting from Newton's Principia at length. Then he provides commentary paragraphs, named "Discussion of Newton's view of time" and "General discussion of the concept of time."

Mach's treatment of Newton takes a somewhat pejorative tone at first. He claims Newton was under the influence of obsolete medieval philosophy. Mach's Newton did not care, contrary to his well-known anti-hypothetical pronouncements, about the investigation of actual facts. Mach articulates his relational account of time in opposition to Newton's substantivalism. When something, like a body A, changes temporally, this means that the conditions determining A depend upon the conditions that determine some other thing, say body B. Oscillations, like that of the pendulum, exemplify clocks. When we consider the pendulum in isolation, we typically do not consider its relation to the Earth. The oscillation is still related to the gravity of the Earth. In examining the pendulum's swing, "we may compare it with any other thing (the conditions of which of course also depend on the position of the earth)," but as we must not necessarily consider its relation to the Earth, "the illusory notion easily arises that all the things with which we compare it are unessential" (SM 223). The bob is at different locations during its swing along the trajectory. We may discern and understand that location in relation to other external things. Moreover, Mach is careful to add, our thoughts and sensations are different with respect to the different locations of the bob. When we forget the relational nature of time, it:

<EXT>appears to be some particular and independent thing, on the progress of which the position of the pendulum depends, while the things that we resort to for comparison and choose at random appear to play a wholly collateral part. But we must not forget that all things in the world are connected with one another and depend on one another, and that we ourselves and all our thoughts are also a part of nature. (SM 223–4)[5]

<TXT>Mach denies that time is the measure of the changes of things. We instead abstract the concept of time from the changes of things. Under such relationalism, there are interconnected motions which provide the notion of uniformity. Mach mentions a common recurring process, the rotation of the Earth. A motion can be uniform with respect to another motion. Whether some motion itself is uniform is a meaningless question. "With just as little justice," Mach comments:

<EXT>we may speak of an "absolute time"—of a time independent of change. This absolute time can be measured by comparison with no motion; it has therefore neither a practical nor a scientific value; and no one is justified in saying that he knows aught about it. It is an idle metaphysical conception. (SM 224)

<TXT>If one clock ticks uniformly, this means it ticks at the same pace in relation to another clock. Whether the sequence of ticks itself is uniform is a senseless question, just as is the question of whether a motion in itself is uniform. The definition of an isochronous interval is fundamentally a relational process. One clock is compared to another clock, not to putative absolute time which marches on independently of external material change.

Karim P. Y. Thébault (2021, 89) details the ways in which the Machian view can be contrasted to the Newtonian. Mach could say that time is mathematical, but only in the sense that the uniform temporal metric is defined in relation to a stable environment. He is also repudiating the substantivalist thesis based on his overall phenomenalist account of concept acquisition. Thébault suggests that this does not imply relationalism:

<EXT>Mach's objections to substantival time do not, of course, equate to an endorsement of relational notions of time. Asserting that time is fundamentally a relation would be just as inconsistent with the phenomenological thesis as taking it to be substance.

<TXT>Erik C. Banks (2014, 55) notes that relationalism was not Mach's ultimate goal. Rather, his "real goal seems to me to be the eliminationist program." I think there is no tension in rejecting substantivalism based on phenomenalist or empiricist principles and then espousing relationalism. After all, relative motions and the interconnections of bodies are all observable. Putative absolute space and time are not. If Mach wants to eliminate space and time altogether, then he could not go on and say that there are spatial or temporal relations. What is perhaps contradictory is the objective to eliminate metaphysics and the objective to develop an ontology of time. Coming up with a relational account of time is to engage in metaphysics.

Instead of completely eliminating the notion of time, Mach might have had something like abstraction in mind. Here we may take a brief sojourn into his <u>Analysis of Sensations</u>, a work published a few years after the <u>Science of Mechanics (the latter was originally published in 1883, the former in 1886)</u>. Mach says that a period of time is not determined in terms of successive identical durations of putative time itself:

<EXT>When the physicist wishes to determine a period of time, he applies, as his standards of measurement, identical processes or processes <u>assumed</u> to be identical, such as vibrations of a pendulum, the rotations of earth, etc. (Mach 1886/1914, 349).

<TXT>We do not have access to uniform flow of time. Therefore, we cannot ascertain that one duration is perfectly equal to another duration. We have instead an access to relative observable motions. Pendulum vibrations and the rotation of the Earth, among others, provide us with measures of temporal intervals. From those intervals we abstract durations. This is an explanation of the origin of our conception of time.

In his Science of Mechanics, Mach continues to further elucidate his denial of Newtonian time. We acquire the idea of time via the interdependence of things. More specifically, we conceive of time relations through our sense-perception and memory.[6] Notions like absolute space, absolute motion—and importantly for this article, absolute time—are "pure mental constructs." Mach contends they cannot be "produced in experience" and are therefore meaningless. "All our principles of mechanics are," Mach generalizes, "experimental knowledge concerning the relative positions and motions of bodies" (SM 229). Say body A alters its state of motion due to an impact with another body B. To make sense of such a dynamic scenario, Mach argues there needs to be other bodies present in reference to the motion of A. If the reference objects were removed, the acceleration of the moving body is left unspecified. An individual body moving in absolute space "would be bereft of all scientific significance" (SM 230). We are in practice always in a situation in which we are surrounded by some number of bodies. In assessing motion, we are not considering only one definite body. We have the false impression that a motion of a body does not depend on the motion of others, and so fail to see the significance of the interconnection of the totality of bodies in our vicinity. Mach ends with a radical proposal concerning the Ptolemaic and Copernican views: Due to the relativity of motion and the conventionality/indexicality of spatial locations, both stances are equally correct. He thinks the latter is only simpler and more practical.

Mach's interpretation of Newton's bucket experiment and the revolving globes thought experiment has been treated many times in the secondary literature. In the reported actual experiment, Newton tied a rope to the handle of a bucket and connected the rope to the ceiling. He twisted the rope as much as it allowed and added water to the bucket. When the bucket is released, one will first see that the level of the water is even. After a while, one will observe an upward motion of the water in the bucket; the water is 'trying' to recede from the axis of its circular motion. Eventually, the water will increase up to a maximum point. At this stage, the water is at rest with respect to the bucket. The concavity of water cannot be explained merely by a reference to observable environment. Therefore, Newton points out in the Scholium to the Definitions:

<EXT>that endeavor [of receding from the axis of circular motion] does not depend on the change of position of the water with respect to surrounding bodies, and thus true circular motion cannot be determined by means of such changes of position.

<TXT>Say two balls, connected with a chord, revolve around a common center of gravity. The "endeavor" to recede from the axis of motion can be computed from the tension of the chord. If a force is exerted on one of the balls, it would increase or decrease the quantity of circular motion. If the force is exerted on the face of the ball so to increase the rotation, the tension of the chord would increase, and vice versa for slowing down the ball by pushing the other face. "In this way," Newton concludes in the Scholium to the Definitions, "both the quantity and the direction of this circular motion could be found in any immense vacuum, where nothing external and sensible existed with which the balls could be compared." The tension of the chord, even in an otherwise completely empty space, indicates absolute rotational motion of a given magnitude and direction.

According to Mach, the forces that produce the upward motion in the bucket are due to the mass of the Earth and massy distant bodies. The experiment is not done in isolation, so we simply do not know what the surface of the water would be if all other bodies were removed. Motions are relative to the entirety of what physically exists. "The one experiment only lies before us, and our business is, to bring it into accord with other facts known to us, and not with the arbitrary fictions of our imagination" (SM 232).

Howard Stein (1977, 14) calls Mach's position "abusive empiricism." He thinks Mach is overly critical of Newton and lays down methodological standards that are practically impossible. Stein takes Mach to be involved in a polemical phenomenalist critique of a physical theory. Stein points out that Newton's bucket experiment involves different stages: in the beginning the rotational velocity is zero, but later it is maximal. The surface of the water is flat when the water is at rest relative to the Earth. At the final stage, the surface is concave when the water is in motion relative to the Earth. The dynamic phenomenon is due to absolute, not relative rotation. Here Stein contextualizes Newton's argument. Newton was probably engaged in a dialogue with Descartes' mechanical theory of motion which requires contiguity. Generation of absolute or true motion for Descartes means that one body touches another in its vicinity. "<u>This</u> notion," Stein (1977, 15) emphasizes, "the bucket experiment quite convincingly shows not to be the appropriate one to serve as the basis for dynamically theory."[7]

Stein admits Newton's argument does not show that there is absolute rotation of water in the final state of the bucket spinning. Newton does not rule out the role of the Earth. Stein criticizes Mach's insistence to take into account distant stars. Mach asks us to remember that absolute rotation means nothing "except <u>relative rotation with respect to the fixed stars</u>" (SM 512). He asks rhetorically: "Can we fix Newton's bucket of water, rotate the fixed stars, and <u>then</u> prove the absence of centrifugal forces?" (SM 512). We cannot carry out such an experiment. Mach calls the whole idea "meaningless." The two cases are empirically indistinguishable, so Newton's distinction is only an illusion (SM 512). Stein thinks that here

Mach violates his own principle of the economy of thought.[8] It is not reasonable or requisite to incorporate everything in the universe when assessing a particular physical phenomenon: “if we need not bring the stars in everywhere, why here? And why the stars rather than the earth?” (Stein 1977, 16).

Stein (1977, 18–9) is also careful to assess the implication of Mach’s argument. That argument is agnostic in spirit. If all the mass of the universe, including distant stars, were removed, there would be no way of knowing how the water in the bucket moves. If the universe is differently arranged, the surface of the water might be different. This is in itself a very weak claim. Sure, new discoveries made in different circumstances may lead to a revision of the theory. Mach neither devises a new theory nor provides evidence for the view that the older physical theory should be revised. He only mentions this possibility.

Mach’s relational argument came to be called Mach’s principle. It is plausible that Moritz Schlick was the first to use the term das Machsche Prinzip explicitly.[9] In 1912, Albert Einstein, in reference to the section on “Newton’s views of time, space, and motion” in The Science of Mechanics, wrote: “ . . . the entire inertia of a point mass is the effect of the presence of all other masses, deriving from a kind of interaction with the latter” (translation in Einstein Studies, Volume 6, Mach’s Principle). John D. Norton (1995, 13–4) argues that what we call Mach’s principle should be separated from Mach’s critique. The two sentences below from Science of Mechanics (232) can be separated as follows:

<EXT>Mach’s principle. “Newton’s experiment with the rotating vessel of water simply informs us, that the relative rotation of the water with respect to the sides of the vessel produces no noticeable centrifugal forces, but that such forces are produced by its relative rotation with respect to the mass of the earth and the other celestial bodies.”

<TXT>Mach’s critique. “No one is competent to say how the experiment would turn out if the sides of the vessel increased in thickness and mass till they were ultimately several leagues thick."

Mach's principle establishes that the rotation of the water occurs in relation to other bodies. Various significant masses are involved, so their role cannot be dismissed. Mach's critique establishes that the mass of the vessel matters: the upward motion of water could come about because the mass and size of the bucket itself is the reason for the centrifugal forces. Somewhat similarly to Stein, Norton (1995, 14) also indicates the circularity of Mach's reasoning. On the one hand, Mach criticizes Newton in assuming what could happen in an otherwise empty space. On the other hand, Mach states that if the bucket increases in size and mass, that could produce the inertial effect within the bucket. Mach both condemns and supports speculation.

Norton considers the option that Mach does not set forth any new mechanical principles but that he redescribes Newtonian mechanics. This is consistent with Mach's own admission in the beginning of his monograph. Later, in the section "The achievements of Newton," he took Newton to have "completed the formal enunciation of the mechanical principles now generally accepted," so that since Newton's "time no essentially new principle has been stated" (SM 187). Everything accomplished in mechanics, in Mach's view, has been a development of Newton's laws. What Mach wishes to do is to state these laws without a reference to absolute notions of space and time. They are for Mach superfluous metaphysical additions. His "project is clearly just one of redescription of existing laws and not the proposal of a new mechanism," Norton (1995, 17) sums up. Mach's positive account of the existence of inertial effects amounts to no more than an argument for the functional dependence of observable variables, like water's surface and distant stars.

Eric C. Banks (2003) and Lydia Patton (2019) argue that Mach's "economy of science" does not resort to "abusive empiricism" or paradoxical reasoning which both affirms and denies speculative theoretical constructs. In the formulation of Patton (2019, 341), we can distinguish natural hypothetical reasoning and artificial hypothetical reasoning. The former is a permissible form of hypothesizing, whereas the latter is not. The following paragraph from the Science of Mechanics (491–2) clarifies Mach's positive account of hypothetical reasoning:

When we mentally add to those actions of a human being which we can perceive, sensations and ideas like our own which we cannot perceive, the object of the idea we so form is economical. The idea makes experience intelligible to us; it supplements and supplants experience. This idea is not regarded as a great scientific discovery, only because its formation is so natural that every child conceives it. Now, this is exactly what we do when we imagine a moving body which has just disappeared behind a pillar, or a comet at the moment invisible, as continuing its motion and retaining its previously observed properties. We do this that we may not be surprised by its reappearance. We fill out the gaps in experience by the ideas that experience suggests.

Patton applies Mach's permissible form of hypothesizing to the bucket experiment. We do have experiences of massy objects in our vicinity, like the Earth. We also could have experiences of a great many distant objects, like stars not observable with contemporaneous technology. We could not have an experience of absolute immaterial, insensible space. As this article focuses on time, we may interpret Mach by saying that the notion of invisible, immaterial time itself which is independent of any external change is an instance of artificial hypothetical reasoning.

Does Mach's criticism of Newton have merit? Stein would say no. He thinks Mach sets impossible standards. Newton's absolute time is certainly not an idle metaphysical conception that is irrelevant for his scientific practice. "Such critical failure," Stein (1977, 14) has it, "is to be seen in Mach whenever he engages on phenomenalistic grounds in polemic against a physical theory." Mach calls atoms mental artifices (more about atoms in a while), much the same way he calls absolute time a mere mental construct.

Critics are right to point out that Mach did not fully appreciate the scientific context of Newtonian time. It is not a trifling metaphysical notion. Absolute time is deeply connected to his mathematical physics, to his method of fluxions (Arthur 1995) and laws of motion (DiSalle 2002). Yet Mach insisted that in principle the utterly unobservable, immaterial entities should not be allowed in physics. A concept of time that is acceptable in physics should somehow be rendered observable. It is interesting that such an empirical requirement was productive of the development of the special theory of relativity.[10] With Einstein the concept of time became considered empirical. This is apparent in Einstein's thought experiment, which utilizes flashes of light in mirrors (Einstein 1920; Slavov 2019). Unlike Newton's self-existing flow, time in special relativity is physical. This is apparent already in the conventionality of simultaneity of Einstein's original 1905 publication. In that context, time is understood by means of readings of clocks and signals travelling between them.

<T1HD>4. But what about the atoms?

<TXT>Mach rejected atoms by using phenomenalist arguments. In his Science of Mechanics (492), he puts it as follows: "Atoms cannot be perceived by the senses; like all substances, they are things of thought." Atoms do not exist out there in the mind-independent world. They are mental artifices. The atomic theory is a mathematical model which facilitates "the mental reproduction of facts" (492).

Although the idea of atomism goes back to antiquity, the 19th century atomic theory revolved around the kinetic theory of gases. This theory maintains gases are made of molecules, which in turn are the compounds of atoms. Statistical calculations on the velocity and collisions of the molecules explains observable macroscopic phenomena like heat and pressure. These computations also predict new phenomenon like viscosity (Bächtold 2010, 2). Mach’s position on the atomic theory is clear in his 1891 article “Some Questions of Psycho-Physics. Sensations and the Elements of Reality.”

In that article, Mach begins by explaining how in his view “colors, sounds, pressures” and the like, are the simplest component parts, the elements which the world consists of. When someone sees a tree with green (A) leaves and a hard (B) gray (C) trunk, “A B C are elements of the world.” Mach explains:

<EXT>I say elements—and not sensations, also not motions—because it is not my purpose at this place to arrive at either a psychological or a physiological or a physical theory, but to proceed descriptively. The every-day man, indeed, takes greenness, grayness, hardness, or complexes thereof it may be, for constituent parts of the world—for he does not trouble himself about a psychologico-physiological theory—and does not learn moreover anything more about the world; from his point of view he is right. Similarly, for the descriptive physicist the question is also one merely of the dependencies of A B C . . . on one another; for him too A B C . . ., or complexes thereof, are and remain constituent parts of the world (Mach 1891, 394–5).

<TXT>Next, he articulates his monist stance:

<EXT>According to my conception, therefore, the same A B C . . . is both element of the world (the “outer” world, namely) and element of feeling. The question how feeling arises out of the physical element has for me no significance, since both are one and the same [..] It is not two sides of the same paper [. . .] but simply the same thing (Mach 1891, 395).

<TXT>Mach (1981, 395–6) tells the reader how molecules and atoms are not perceivable, but hypothetical in the bad sense of the word ‘hypothetical’. In his terminology, the atomic theory is involved with artificial, not natural hypothesizing. We do not perceive the motion of atomic particles: “A motion is either perceptible by the senses, as the displacing of a chair in a room or the vibration of a string, or it is only supplied, added (hypothetical), like the oscillation of the ether, the motion of molecules and atoms, and so forth." In "the case of the motions of atoms and molecules," we do not perceive their motions, so "we have to do with a noumenon, that is, a mere mental auxiliary, an artificial expedient, the purpose of which is solely to indicate, to represent, after the fashion of a model, the connection between A B C . . ., to make it more familiar to us." Whereas ordinary perceptual motions exemplify relations between elements A, B and C, the hypothetical motions of atoms do not. Atoms are not the elements of the world. They are figments of our imagination. Atoms are not legitimate postulates for explaining macroscopic kinetic phenomena in the same way as the hypothetical ethereal medium is not a legitimate postulate for explaining electrodynamic phenomena.

Manuel Bächtold (2010) stresses that Mach rejects the independent existence of atoms. Mach thinks the notion of a thing-in-itself is inconsistent. It does not matter whether the object in question is macroscopic or microscopic. ''Thing, body, matter, are nothing apart from the combinations of the elements—the colours, sounds, and so forth—nothing apart from their so-called attributes,'' Mach (1886/1914, 6–7) writes in the Analysis of Sensations. If we completely abstract perceptions, appearances, or attributes, we are left with nothingness.[11] There is no legitimate way to distinguish between phenomena and noumena. We can know something about an object only if it is related to the perceptual phenomena. For Mach, sensations are the basis of all factual knowledge. This is the quintessential point of Mach's denial of atoms. Bächtold (2010, 6) clarifies:

<EXT>. . . can we say that atoms are real (or exist)? If real is understood in the strong sense of being constituents of the external world, or in other words, as existing independently of our minds and our actions, then Mach's answer is clearly negative. In his view, only sensations and their connexions are real, not the abstractions constructed on the basis of them.[12]

<TXT>Mach rejected both absolute time and atoms in the substantial sense: there is no time which exists itself, and there are no atoms which exist by themselves. In providing his arguments, he relied on reasons that we might characterize as "positivist" or "phenomenalist." I reckon there are only a few philosophers nowadays who would subscribe to positivism or phenomenalism. The putative time itself is not apparent to our senses, and neither are atoms. This might make us think that both Mach's critique of Newtonian time and the microscopic atomic realm are obsolete. In contemporary debates concerning time, Tim Maudlin expresses his sympathies toward Newton. According to his substantivalist position, the passage of time is independent of external change:

<EXT>The passage of time is a fundamentally asymmetric feature of time, in virtue of which all motion and change occurs, that is, things only change because time passes. I believe that time can pass without there being any change, or any other change than the passage of time itself, i.e. change in what time it is (Maudlin 2018, 1808).

<TXT>Maudlin's position is updated to fit relativity in such a way that he takes passage of time and the laws of nature as the fundamental entities of the universe (Maudlin 2020). Like Newton's time, the passing of time cannot be observed. Maudlin (2012: 46) anticipates this objection:

<EXT>. . . physics is evidently in the business of postulating unobservable entities in service of explaining observable behavior. The postulation is always risky, but, as the atomic hypothesis illustrates, the risk can sometimes pay off handsomely. Newton knew that absolute space and time are not, in themselves, observable, but he also explained how postulating them could help explain the observable facts. Why is this any worse than postulating atoms?

<TXT>I think putative absolute time and atoms are very different kinds of entities. The former cannot be observed, measured, or manipulated in any way. Not even in principle. Newton's time is immaterial. How could human beings device technologies that track the flow of non-physical time? Measuring devices are physical instruments, so they can detect only physical processes.[13] Atoms are completely different. With various technologies, atoms have become detectable. It is hard to imagine contemporary natural sciences, or a great many devices and medicines, without the atomic structure of matter. Yet no science requires an absolute time. At least not in the sense of self-existing flow from past to future via the present. Science and tech can do without absolute time but not without atoms.

<T1HD>5. Conclusion

<TXT>Mach insisted that “time is an abstraction, at which we arrive by means of the changes of things” (SM 224). The putative absolute time is thought to exist and flow independently of any external change. “This absolute time,” Mach (Ibid.) concludes, “can be measured by comparison with no motion; it has therefore neither a practical nor a scientific value; and no one is justified in saying that he knows aught about it. It is an idle metaphysical conception.”

The last sentence of the quote above is certainly too harsh. Mach overlooked many of Newton’s physical, mathematical and theological considerations that back up his account of substantial time. Mach also provided an alternative ontological account of time, according to which time is a relational feature of the world, a relation among interconnected bodies. This is a metaphysical notion; it is hard to see how it could be metaphysically neutral.

As is well-known, Mach contributed to the development of the theories of relativity. Those theories dispose of absolute time because simultaneity is relative and conventional. Mach did not analyze simultaneity in detail, but he provided an epistemology and an ontology that are at least hospitable to relativity. His epistemic and ontic positions are clearly not suitable for a realist understanding of the atomic theory, let alone subsequent nuclear and high energy physics. However, this should not make us think that his criticism of Newtonian time is merely obsolete phenomenalism or positivism.

<**Captions start here**>

Figure 1. Kepler's area law idealized.

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<NTXT>[1] For the three stages of the argument, see Belkind (2012) and Harper (2016).

[2] Thébault (2021, 87) notes that Newton’s mathematical time “provides a single quantitative measure of duration that is applicable to all motions.” One can thus apply one quantity of time to any kind of body, independent of its trajectory or location.

[3]In paragraph 59 (p. 20) he puts it as follows:

<NEXT>But whereas we need to consider the Time here, any farther than as it is expounded and measured by an equable local Motion; and besides, whereas only Quantities of the same kind can be compared together, and also their Velocities of Increase and Decrease; Therefore in what follows I shall have no regard to Time formally consider’d, but I shall suppose some one of the Quantities proposed, being of the same kind, to be increased by an equable Fluxion, to which the rest may be referr’d, as it were to Time; and therefore, by way of

Analogy, it may not improperly receive the name of Time. Whenever therefore the word Time occurs in what follows, (which for the sake of perspicuity and distinction I have sometimes used), by that Word I would not have it understood as if I meant Time in its formal Acceptation, but only that other Quantity, by the equable Increase or Fluxion whereof, Time is expounded and measured.

<NTXT>[4] A somewhat similar position is articulated by Sklar (1990) and criticized by Ducheyne (2001).

[5] Thébault (2021, 88–9) has collected quotes that indicate Mach's emphasis on interdependence.

[6] See his Analysis of Sensations: "Space and time, closely considered, stand, as regards physiology, for special kinds of sensations; but, as regards physics, they stand for functional dependencies upon one another of the elements characterized by the sensations" (Mach 1866/1914, 348).

[7] Rynasiewicz (1995) argues that the bucket experiment shows how absolute and relative motion can, in contrast to Descartes mechanical theory of motion, be distinguished "by their properties, causes, and effects."

[8] In the definition of Banks (2004, 23), the economy of thought means:

<NEXT>As it is usually understood, that doctrine holds that scientific laws and abstract class terms are tools for compiling and organizing experience by means of the fewest possible concepts, a mastery that is useful for the prediction and control of events.

<NTXT>[9] Schlick noted in 1915: "the cause of inertia must be assumed to be an interaction of masses." Quoted from Norton (1995, 47).

[10] Gereon Wolters (2019) argues that Mach was not, as is commonly assumed, anti-relativity. He was not a theoretical physicist, and his health was in a poor condition in the beginning of the 20th century. The famous sentence that denounces relativity, Wolters suggests, could be a

forgery made by Ernst's son Ludwig Mach. I do not take a stance on the forgery issue.

[11] This is of course reminiscent of Berkeley's and Hume's critiques of the notion of substance.

[12] Bächtold (2010, 16) shows that Mach eventually became more tolerant concerning the atomic theory. Mach acknowledged "the scientific success of atomism: it is 'a good working hypothesis,' or it is 'manifold and useful.'" He then warns against an ontological belief concerning the existence of atoms: one should not "treat atoms as realities."

[13] See Prosser's (2016) detector thought experiment argument.