Journal of Aetherometric Research 1, 6:1-16 (May 2006)

A running commentary on Einstein's "Aether and the Theory of Relativity"

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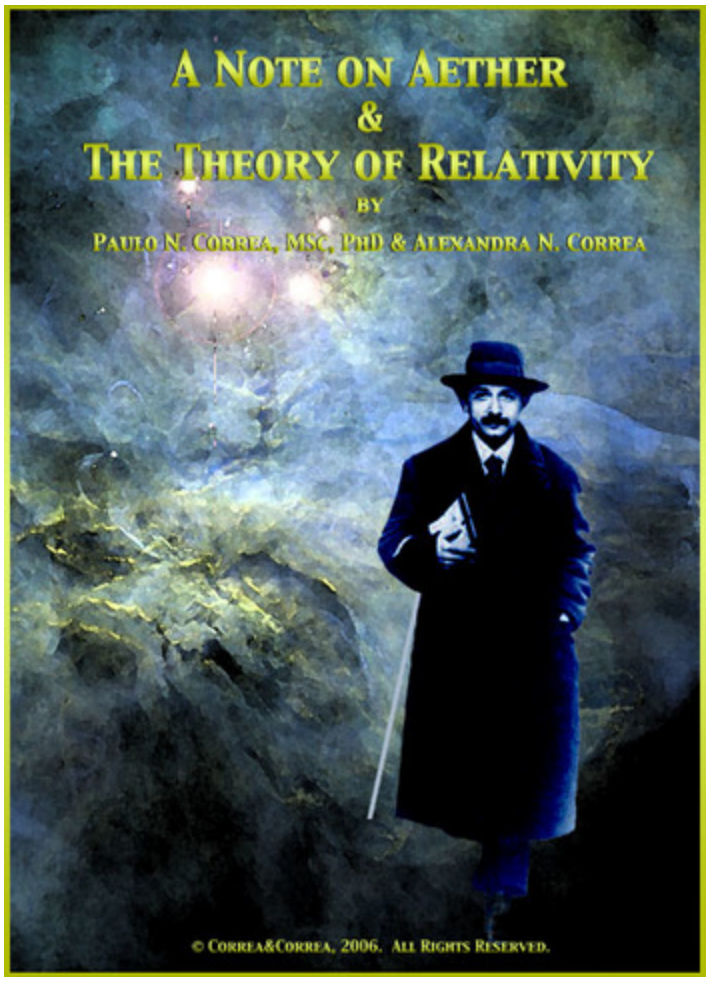

Note. Before reading this commented version, you may want to read Einstein's text by itself.

Aether and the Theory of Relativity

by Albert Einstein, PhD

Address delivered on May 5th, 1920, at the University of Leyden in the Netherlands.

How does it come about that alongside of the idea of ponderable Matter, which is derived by abstraction from everyday life, the physicists set the idea of the existence of another kind of Matter, the Aether? The explanation is probably to be sought in those phenomena which have given rise to the theory of action at a distance, and in the properties of light which have led to the undulatory theory. Let us devote a little while to the consideration of these two subjects.

Einstein begins by presenting the two coordinates of the old theory of the stationary Aether: Newton's postulate of action at a distance (already criticized by Descartes) and the undulatory solution to the problem of the transmission of light.

Outside of physics we know nothing of action at a distance. When we try to connect cause and effect in the experiences which natural objects afford us, it seems at first as if there were no other mutual actions than those of immediate contact, e.g. the communication of motion by impact, push and pull, heating or inducing combustion by means of a flame, etc.

Einstein underlines how, on one hand, only the assumption of the contiguity of a material substance or a medium is in agreement with sense-experience or sense-perception, and how, on the other hand, the notion of action at a distance stands at variance with sense-experience.

It is true that even in everyday experience weight, which is in a sense action at a distance, plays a very important part. But since in daily experience the weight of bodies meets us as something constant, something not linked to any cause which is variable in time or place, we do not in everyday life speculate as to the cause of gravity, and therefore do not become conscious of its character as action at a distance. It was Newton's theory of gravitation that first assigned a cause for gravity by interpreting it as action at a distance, proceeding from masses. Newton's theory is probably the greatest stride ever made in the effort towards the causal nexus of natural phenomena. And yet this theory evoked a lively sense of discomfort among Newton's contemporaries, because it seemed to be in conflict with the principle springing from the rest of experience, that there can be reciprocal action only through contact, and not through immediate action at a distance.

Einstein here returns to Descartes' criticism of Newton's postulate of action at a distance. The dualism in the physical description of nature that he next describes relates to the alternative between two explanations - one, Newtonian, that takes recourse to forces which mysteriously propagate across space, and the other, Cartesian, that requires contiguity of Matter or medium for the transmission of force:

It is only with reluctance that man's desire for knowledge endures a dualism of this kind. How was unity to be preserved in his comprehension of the forces of nature? Either by trying to look upon contact forces as being themselves distant forces which admittedly are observable only at a very small distance and this was the road which Newton's followers, who were entirely under the spell of his doctrine, mostly preferred to take; or by assuming that the Newtonian action at a distance is only apparently immediate action at a distance, but in truth is conveyed by a medium permeating space, whether by movements or by elastic deformation of this medium. Thus the endeavour toward a unified view of the nature of forces leads [in the second arm of the dualism, that is] to the hypothesis of an Aether. This hypothesis, to be sure, did not at first bring with it any advance in the theory of gravitation or in physics generally, so that it became customary to treat Newton's law of force as an axiom not further reducible. But the Aether hypothesis was bound always to play some part in physical science, even if at first only a latent part.

Effectively, Einstein mixes the two traditions - Cartesian and Newtonian - somewhat in the preceding paragraph, given that they eventually settled, each in its own way, on a concept of a deformable Aether that serves as medium for both Light and Gravity.

When in the first half of the nineteenth century the far-reaching similarity was revealed which subsists between the properties of light and those of elastic waves in ponderable bodies, the Aether hypothesis found fresh support.

The merger of the two distinct traditions, Cartesian and Newtonian, into the classical theory of an Aether was - more correctly - the result of advancements in the study of the transmission of light, and this is what permitted the enunciation of the concept of the *stationary luminiferous Aether*:

It appeared beyond question that light must be interpreted as a vibratory process in an elastic, inert medium filling up universal space.

Notice how Einstein carefully crafts this statement: space, conceived as universal, is an empty form where Light propagates by virtue of a medium that 'fills up' that 'universal space'.

It also seemed to be a necessary consequence of the fact that light is capable of polarisation that this medium, the Aether, must be of the nature of a solid body, because transverse waves are not possible in a fluid, but only in a solid.

Einstein is correct in emphasizing that a solid phase Aether "*seemed* to be a necessary consequence" of light polarization, but he does not exactly explain how this "seemingness" was not in fact necessary: transverse waves are possible at fluid interfaces; hence, the solid phase Aether was necessary *only* for the *undisturbed* propagation of Light.

Thus the physicists were bound to arrive at the theory of the "quasi-rigid" luminiferous Aether, the parts of which can carry out no movements relatively to one another except the small movements of deformation which correspond to light-waves.

In essence, then, the luminiferous Aether is conceived as an immobile (stationary) and rigid (solid phase) Aether occupying an absolute space -

This theory - also called the theory of the *stationary luminiferous Aether* - moreover found a strong support in an experiment which is also of fundamental importance in the special theory of relativity, the experiment of Fizeau, from which one was obliged to infer that the luminiferous Aether does not take part in the movements of bodies.

The interpretation of Fizeau's experiment is somewhat controversial: all it showed was that the Aether was not dragged by the motion of a body, a finding that by itself should have denied the existence of a stationary deformable Aether. But Fizeau's experiment also showed that if a body possessed an immanent 'aura' or 'field' of Aether, the latter moved with the body and indissociably from it.

The phenomenon of aberration also favoured the theory of the quasi-rigid Aether.

The development of the theory of electricity along the path opened up by Maxwell and Lorentz gave the development of our ideas concerning the Aether quite a peculiar and unexpected turn. For Maxwell himself the Aether indeed still had properties which were purely mechanical, although of a much more complicated kind than the mechanical properties of tangible solid bodies. But neither Maxwell nor his followers succeeded in elaborating a mechanical model for

the Aether which might furnish a satisfactory mechanical interpretation of Maxwell's laws of the electro-magnetic field.

Maxwell wasn't exactly after the mechanical properties of the Aether; on the contrary, his notion of an electro-magnetic field was presented as being a non-mechanical property of the Aether, since electric and magnetic properties were not seen as being mechanical. More correctly, then, the action of the Aether medium for Maxwell consisted in the propagation of a state of stress (the *pattern* of the *electro-magnetic field*), as it applied (1) to the mechanical action between electric currents and (2) to magneto-electric induction. The electromagnetic waves transversely propagating across the medium were simply local states of stress or disturbance of the calm Aether crystal. However, Maxwell sought an integration of the mechanical and electro-magnetic properties -

> "It must be carefully borne in mind that we have made only one step in the theory of the action of the medium. We have supposed it to be in a state of stress, but we have not in any way accounted for this stress, or explained how it is maintained. This step, however, seems to me to be an important one, as it explains, by the action of the consecutive parts of the medium, phenomena which were formerly supposed to be explicable only by direct action at a distance. I have not been able to take the next step, namely, to account by mechanical considerations for these stresses in the dielectric. I therefore leave the theory at this point, merely stating what are the other parts of the phenomenon of induction in dielectrics." [1]

The laws were clear and simple, the mechanical interpretations clumsy and contradictory. Almost imperceptibly the theoretical physicists adapted themselves to a situation which, from the standpoint of their mechanical programme, was very depressing. They were particularly influenced by the electro-dynamical investigations of Heinrich Hertz. For whereas they previously had required of a conclusive theory that it should content itself with the fundamental concepts which belong exclusively to mechanics (e.g. densities, velocities, deformations, stresses) they gradually accustomed themselves to admitting electric and magnetic force as fundamental concepts side by side with those of mechanics, without requiring a mechanical interpretation for them. Thus the purely mechanical view of nature was gradually abandoned.

Einstein is correct in seeing this abandonment of the mechanistic viewpoint more as the result of confusion than as the result of a viable new synthesis of mechanical and electromagnetic properties. What Einstein fails to mention is that Hertz inaugurated an era which flattened the problem of the propagation of Light. Even if one is not to distinguish the local production of photons from the transmission of the impulse or stimulus to their production (propagation of Light, *tout court*), there remained - in XIXth century Physics - C.F. Gauss' and B. Riemann's deduction of the transmission of electric potential ('electrostatic') without recourse to a stationary medium; and, as well, C. Neumann's treatment of this transmission as a propagation of potential *from charge to charge*. It was the failure to take into account this transmission of electric potential, let alone to fully appreciate its physics, which precluded the full comprehension of both the propagation of the light-producing stimulus and the transfer of energy from the field to the affected charges. Einstein glosses over this problem. But it cannot be glossed over (it would return later in the XXth century in the form of the Cerenkov equations for the propagation of potential) because Neumann was paradoxically both right and wrong:

- *wrong*, in that the propagation of potential *is the very basis* for the propagation of the stimulus of Light, and *is not* merely or basically an action *of* massbound charge *upon* massbound charge; in fact, as one concludes from Aetherometry, the propagation of potential is the propagation of an electric field, and the field is one that acts upon massbound charges to confer upon them kinetic energy, ie set them into motion;

- *right*, in that the propagation of potential does not abide by the speed of light; indeed it doesn't, since the propagation of potential (1) obeys its own longitudinal electric wave functions, and (2) must couple to charged Matter (massbound charges) so as to accelerate its motion. Moreover, the photons locally generated reflect solely the kinetic states of the moving massbound charges and only the photons comport transverse wave functions.

Finally, Neumann (and Maxwell) were also right in thinking that the potential propagated by the field was a function of e^2/r (where r is the distance between the charges), which boils down to the interaction energy of the superimposing charges.

The paradox is that it is *only* that field which the massbound charges generate as Light (local photons) or pass on, by reabsorption, to other massbound charges as Light, which is *electromagnetic*. But this is just a secondary field (tertiary, really!), *not the field associated with the transmission of electric potential that primarily accelerates those massbound charges*. In fact, the photon or electromagnetic field is only generated when accelerated charges decelerate, when they shed their kinetic energy - not while they absorb field energy to move under acceleration. It follows, therefore, that while the mechanical aspect of the photon was understood as a discharge of the kinetic states of charged massbound particles, the connection between it and the primary electric field failed to be made. If it is the primary electric field that effectively transmits the stimulus of Light, then the transmission of Light is not electromagnetic but dark. Only the production of Light, locally, is electromagnetic, and one is therefore constrained to have to distinguish photon rays from the wave of potential that makes them possible, indirectly, by accelerating the charged massbound particles to begin with. But is this a 'disembodied' wave, as Cerenkov would later pretend, or is this wave part of an electric energy flux which is the real physical sense of the field?

Back to Einstein:

But this change led to a fundamental dualism which in the long-run was insupportable. A way of escape was now sought in the reverse direction, by reducing the principles of mechanics to those of electricity, and this especially as confidence in the strict validity of the equations of Newton's mechanics was shaken by the experiments with beta-rays and rapid cathode rays.

The state of confusion that diluted mechanistic theory led - in Einstein's exposition here - to a new dualism: that of particle and wave descriptions of nature which did not appear to be synthesizable, or compatible. The problem, once more, goes back to the confusion between transmission and production of Light, and just as well to the physical nature of both:

1. Is Light transmitted as waves (transverse) - as undulatory stresses in a stationary medium - as Maxwell thought?

2. Or is Light transmitted as particles hurled across space, as Newton's corpuscular theory of Light held?

And again: what is the nature of Light? What does the eye see - particles impinging on it, or waves of stress deformation that reach it?

Once more, one needs to appreciate that what threw classical physics into disarray was the discovery of Planck's constant for the quantum action of Light. A corpuscular theory of Light would account for its transmission by invoking mechanical properties, and would not necessitate the positing of a medium to occupy space, whereas an undulatory theory of Light would account for its transmission by the stress electromagnetic properties of a medium.

It occurred to no one that the medium itself in part consists of the propagation of potentials, that this propagation is one of electric energy, and it is this that performs the propagation of the stimulus of Light *if there is Matter present in the field* - Matter that can accelerate and decelerate. The medium itself is flux and *in flux*. Moreover, it occurred to no one that the photon-particle never parts company with its electromagnetic field wave (the one that complies with c), but that its electromagnetic field wave is distinct from the *electric field wave* that established the primary field. Thus, the electromagnetic particle is solidary with its electromagnetic wave, and the particle treatment for the photon is directly 'unified' (integrated) with the wave treatment [2]. And thus, also, the electric field wave of potential does not remain disembodied, or separate from its energetic or physical reality - as a wave looking for a particle. It is shown aetherometrically to belong to the massfree charges whose flow constitutes the primary physical reality of the field. The massfree charges are no less particulate than are the massbound charges of Matter. Hence, the electric wave of potential is not separable from the electric charge of massfree energy - from the radiant energy that constitutes the electric field to begin with.

As it necessarily and historically stood, however, the wave and particle treatments of Light remained totally confused, both as to the nature of the primary electric field and its massfree particle-charges, and the nature of the secondary electromagnetic field and its particle-photons. Since massfree energy remains unacknowledged, the primary field is mischaracterized and the nature of reality is ontologically reduced to Matter and the electromagnetic field that it bears:

This dualism still confronts us in unabated form in the theory of Hertz, where Matter appears not only as the bearer of velocities, kinetic energy, and mechanical pressures, but also as the bearer of electromagnetic fields.

This would render the concept of the Aether superfluous: the field arises by the contiguous action of massbound charge on massbound charge, and its nature is photonic or electromagnetic. And indeed, Einstein is about to show how that happened:

Since such fields also occur *in vacuo* - i.e. in free Aether - the Aether also appears as bearer of electromagnetic fields. The Aether appears indistinguishable in its functions from ordinary Matter. Within Matter it takes part in the motion of Matter and in empty space it has everywhere a velocity; so that the Aether has a definitely assigned velocity throughout the whole of space. There is no fundamental difference between Hertz's Aether and ponderable Matter (which in part subsists in the Aether).

Einstein, quite rightly, wonders what Hertz's Aether is if not simply Matter disguised as Aether: it is in variable states of motion, it has assigned velocity of flux, it bears electromagnetic fields (ie generates light directly).

The Hertz theory suffered not only from the defect of ascribing to Matter and Aether, on the one hand mechanical states, and on the other hand electrical states, which do not stand in any conceivable relation to each other; it was also at variance with the result of Fizeau's important experiment on the velocity of the propagation of light in moving fluids, and with other established experimental results.

Such was the state of things when H. A. Lorentz entered upon the scene. He brought theory into harmony with experience by means of a wonderful simplification of theoretical principles. He achieved this, the most important advance in the theory of electricity since Maxwell, by subtracting from the Aether its mechanical, and from Matter its electromagnetic qualities. As in

empty space, so too in the interior of material bodies, the Aether, and not Matter viewed atomistically, was exclusively the seat of electromagnetic fields. According to Lorentz, the elementary particles of Matter alone are capable of carrying out movements; their electromagnetic activity is entirely confined to the carrying of electric charges. Thus Lorentz succeeded in reducing all electromagnetic happenings to Maxwell's equations for free space.

Einstein's comment on Lorentz's theory can be summarized this way: if one confines the electromagnetic field - which is a property of charge - to the Aether, and the mechanics of inertial motion to Matter, then the property of charge affected to Matter is a property of the Aether affected to Matter (ie only *in appearance* a property of Matter), the real property of Matter being its mechanical motion (the property of the charge carriers). The Aether would bear the electromagnetic field as Matter bore kinetic energy. Charge affected to matter was the link.

As to the mechanical nature of the Lorentzian Aether, it may be said of it, in a somewhat playful spirit, that immobility is the only mechanical property of which it has not been deprived by H. A. Lorentz.

In other words: the Lorentzian Aether remains a stationary Aether with respect to which absolute velocities can be measured. That is its only mechanical feature.

It may be added that the whole change in the conception of the Aether which the Special Theory of Relativity brought about, consisted in taking away from the Aether its last mechanical quality, namely, its immobility. How this is to be understood will forthwith be expounded. mechanical feature.

The Spacetime theory and the kinematics of the Special Theory of Relativity were modelled on the Maxwell-Lorentz theory of the electromagnetic field. This theory therefore satisfies the conditions of the Special Theory of Relativity, but when viewed from the latter it acquires a novel aspect. For if K be a system of co-ordinates relatively to which the Lorentzian Aether is at rest, the Maxwell-Lorentz equations are valid primarily with reference to K. But by the Special Theory of Relativity the same equations without any change of meaning also hold in relation to any new system of co-ordinates K' which is moving in uniform translation relatively to K. Now comes the anxious question: Why must I in the theory distinguish the K system above all K' systems, which are physically equivalent to it in all respects, by assuming that the Aether is at rest relatively to the K system? For the theoretician such an asymmetry in the theoretical structure, with no corresponding asymmetry in the system of experience, is intolerable. If we assume the Aether to be at rest relatively to K, but in motion relatively to K', the physical equivalence of K and K' seems to me from the logical standpoint, not indeed downright incorrect, but nevertheless inacceptable.

Einstein, here, puts his emphasis on what is arbitrary regarding the axiom of a stationary Aether: why should an act of referentiality give preference to a system of coordinates because it is assumed that this system is at rest? He questions how this can be, since one can prove by Special Relativity that the same equations of physics also hold for another system of coordinates that is moving *at constant speed* with respect to the priviledged system. He places the argument, therefore, in the realm of so- called 'inertial motion': why should one privilege an inertial frame of reference, since it is exchangeable with any other inertial frame of reference? So how can one say that one system is at rest and the other is moving? Rest is phenomenological (it exists by the act of referentiality) and movement is relative, as no absolute speed can be measured.

In this manner, the absolute inertia or immobility of the Lorentzian Aether is expunged, since its system of coordinates can be seen as being no less in motion than any other system of coordinates is, or must be.

The next position which it was possible to take up in face of this state of things appeared to be the following. The Aether does not exist at all. The electromagnetic fields are not states of a medium, and are not bound down to any bearer, but they are independent realities which are not reducible to anything else, exactly like the atoms of ponderable Matter. This conception suggests itself the more readily as, according to Lorentz's theory, electromagnetic radiation, like ponderable Matter, brings impulse and energy with it, and as, according to the Special Theory of Relativity, both Matter and radiation are but special forms of distributed energy, ponderable mass losing its isolation and appearing as a special form of energy.

Einstein, very carefully, alludes to the first outcome of Special Relativity - the one which stung the world of Official Science in the early 1900's: that since no inertial system of coordinates could be privileged, there was no immobile Aether, nor any theoretical, physical or mechanical need for an Aether. The electromagnetic field is not a state of stress of a medium - nor does it have to be borne by anything else, Aether or Matter. Wave-energy could have its own existence without being a mere appearance, a phenomenon (as long as one thought of space as being an abstract universal reality, a container that could be emptied). All that would remain, then, would be ponderable Matter and imponderable electromagnetic radiation (light particles would have to be massless in this scenario).

But this is not where Einstein's own path led him, nor the direction he charted for Relativity; so he cautions against this very view:

More careful reflection teaches us, however, that the Special Theory of Relativity does not compel us to deny the Aether. We may assume the existence of an Aether; only we must give up ascribing a definite state of motion to it, i.e. we must by abstraction take from it the last mechanical characteristic which Lorentz had still left it. We shall see later that this point of view, the conceivability of which I shall at once endeavour to make more intelligible by a somewhat halting comparison, is justified by the results of the General Theory of Relativity.

In other words, one should consider Special Relativity carefully and realize that all it tells us is that there may still be an Aether, but not one with a uniform state of motion, specifically, one which is absolutely immobile - a stationary Aether. Moreover, says Einstein, the very General Theory of Relativity itself leads to a conception of a dynamic Aether comporting varied states of motion. Why haven't commentators of Einstein - or those of this text - ever drawn out these elements which make at once evident the real direction of Einstein's thought? Here, we find precisely so many of the precursors of the essential traits of Aetherometry: the nonexistence of a stationary Aether; the existence of a dynamic Aether; the field contiguity as an energy flux and an energy continuum. But will Einstein ever find his way here? Will he come to uncover the massfree nature of the dynamic Aether in its electric, electromagnetic and gravitational interactions?

He continues:

Think of waves on the surface of water. Here we can describe two entirely different things. Either we may observe how the undulatory surface forming the boundary between water and air alters in the course of time; or else - with the help of small floats, for instance - we can observe how the position of the separate particles of water alters in the course of time. If the existence of such

floats for tracking the motion of the particles of a fluid were a fundamental impossibility in physics - if, in fact, nothing else whatever were observable than the shape of the space occupied by the water as it varies in time - we should have no ground for the assumption that water consists of movable particles. But all the same we could characterize it as a medium.

Einstein is aware that the notion of particles is intimately tied in to the inertia of (floating) bodies and the atomist view of matter. This precludes the concept of massfree particles. So, he wants us to imagine a world where neither Matter nor particles could be detected - in such a world, he tells us, one would still be able to think about a medium and observe the undulations of its surfaces or the shape of the space it occupied. He invites us to think of the electromagnetic field as a dematerialized reality where the motions of the lines of force are the equivalent of the motions of the particles of Matter in the world of Matter:

We have something like this in the electromagnetic field. For we may picture the field to ourselves as consisting of lines of force. If we wish to interpret these lines of force to ourselves as something material in the ordinary sense, we are tempted to interpret the dynamic processes as motions of these lines of force, such that each separate line of force is tracked through the course of time [and thus is treated as a particle]. It is well known, however, that this way of regarding the electromagnetic field leads to contradictions.

Generalising we must say this: there may be supposed to be extended physical objects to which the idea of motion cannot be applied. They may not be thought of as consisting of particles which allow themselves to be separately tracked through time. In Minkowski's idiom this is expressed as follows: not every extended conformation in the four-dimensional world can be regarded as composed of worldthreads. The Special Theory of Relativity forbids us to assume the Aether to consist of particles observable through time, but the hypothesis of Aether in itself is not in conflict with the Special Theory of Relativity. Only we must be on our guard against ascribing a state of motion to the Aether.

This difficult paragraph must be carefully teased apart: in essence, Einstein seeks to define a physical reality of an ontological nature, one to which the very idea of motion may not be ascribed - and not just a specific state of motion such as that of an absolute immobility. He really is not seeking a dynamic Aether anymore, but a pure physical form for the Spacetime continuum. In fact, he now hardens the argument of Special Relativity to reduce the possibility of particles solely to the world of Matter; the Aether Einstein speaks of is proscribed from being composed by particles "observeable through time". Hence, it is a noninertial, nonparticulate and conformational Aether - since it is distinct from Matter, cannot be made up of particles, and has no state or states of motion.

Certainly, from the standpoint of the Special Theory of Relativity, the Aether hypothesis appears at first to be an empty hypothesis. In the equations of the electromagnetic field there occur, in addition to the densities of the electric charge, *only* the intensities of the field. The path of electromagnetic processes *in vacuo* appears to be completely determined by these equations, uninfluenced by other physical quantities. The electromagnetic fields appear as ultimate, irreducible realities, and at first it seems superfluous to postulate a homogeneous, isotropic Aether-medium, and to envisage electromagnetic fields as states of this medium.

But on the other hand there is a weighty argument to be adduced in favour of the Aether hypothesis. To deny the Aether is ultimately to assume that empty space has no physical qualities whatever.

Space empty of Matter, space qua space, perceived and sensed, cannot be devoid of physical qualities. But will Einstein succeed in formulating an adequate treatment of the physical qualities of space? Or will he reduce them to ontological and conformational (geometric and topological) criteria? That is, after all, the question. Can a purely geometrical treatment of Space form the basis for the contiguity of spaces or a continuum of reality? Isn't an energy-based treatment of Space necessary and, moreover, doesn't it necessarily have to involve the concept of massfree energy and its phase superimposition? Einstein, rather discretely, now returns to the question of motion - he first draws out what happens with systems of coordinates that are subject to acceleration, as in the problem of rotation which preoccupies General Relativity:

The fundamental facts of mechanics do not harmonize with this view [ie, that empty space has no physical characteristics]. For the mechanical behaviour of a corporeal system hovering freely in empty space depends not only on relative positions (distances) and relative velocities, but also on its state of rotation, which physically may be taken as a characteristic not appertaining to the system in itself.

In this fashion, Einstein will manage not to have to consider the state of rotation as seat of a kinetic energy that belongs to the material system of the rotating body; instead, he will approach it as a physical property of space, nearly agreeing with Newton on this:

In order to be able to look upon the rotation of the system, at least formally, as something real, Newton objectivizes space. Since he classes his absolute space together with real things, for him rotation relative to an absolute space is also something real. Newton might no less well have called his absolute space "Aether"; what is essential is merely that besides observable objects, another thing, which is not perceptible, must be looked upon as real, to enable acceleration or rotation to be looked upon as something real.

Einstein argues therefore that space does have physical characteristics - detected by the properties of rotation - which belong to the nature of an Aether. Moreover, Einstein notes that the relationist argument of Mach cannot itself be construed as an argument against the conceptualization of the Aether that Einstein is proposing. In fact, he argues, an inertial resistance with respect to distant stars or the totality of the masses in the universe will require action at a distance, which brings one right back to the argument concerning the nature of an Aether capable of transmitting - not the force of gravity - but the mysterious property of inertia [**3**]:

It is true that Mach tried to avoid having to accept as real something which is not observable by endeavouring to substitute in mechanics a mean acceleration with reference to the totality of the masses in the universe in place of an acceleration with reference to absolute space. But inertial resistance opposed to relative acceleration of distant masses presupposes action at a distance; and as the modern physicist does not believe that he may accept this action at a distance, he comes back once more, if he follows Mach, to the Aether, which has to serve as medium for the effects of inertia. But this conception of the Aether to which we are led by Mach's way of thinking differs essentially from the Aether as conceived by Newton, by Fresnel, and by Lorentz. Mach's Aether not only *conditions* the behaviour of inert masses, but *is also conditioned* in its state by them.

So what is the difference between Newton's 'absolute space' and Mach's Aether? Einstein has answered - that Mach's Aether interacts with Matter, with inert mass, and that the physical

properties of space are revealed by the Aether's interaction with Matter, conditioning Matter and being conditioned by it. But what exactly does this mean? For, after all, neither in this lecture nor in his writings does Einstein explain what inertia is, how it is transmitted or how it differs from the transmission of gravity. If inertia and gravity are space properties or properties of an Aether, how do they relate to its energy? Exactly how is the Aether of the General Theory of Relativity conditioned and conditioning?

Mach's idea finds its full development in the Aether of the General Theory of Relativity. According to this theory the metric qualities of the continuum of Spacetime differ in the environment of different points of Spacetime, and are partly conditioned by the Matter existing outside of the territory under consideration. This Space-time variability of the reciprocal relations of the standards of space and time, or, perhaps, the recognition of the fact that "empty space" in its physical relation is neither homogeneous nor isotropic, compelling us to describe its state by ten functions (the gravitation potentials $g_{\mu\upsilon}$), has, I think, finally disposed of the view that space is physically empty. But therewith the conception of the Aether has again acquired an intelligible content, although this content differs widely from that of the Aether of the mechanical undulatory theory of light. The Aether of the General Theory of Relativity is a medium which is itself devoid of *all* mechanical and kinemassic qualities, but helps to determine mechanical (and electromagnetic) events.

In this crucial passage, Einstein makes a series of propositions which Aetherometry assesses critically as being distinct. The metric qualities, or simply the measure, in different territories of the real Space-Time continuum may differ, and do differ, since that difference is effectively a consequence of the energy density of a given space locality and the energy flux through that locality. The locality itself is an abstraction, because it is Space which is a physical property of energy, one of its manifolds, and not Space that contains energy. Only in abstraction does a space, an abstract space, contain energy. Accordingly, Space, concrete Space qua physical property of energy, is the product of the superimposition of energy - wave energy - and can never be treated as homogenous or isotropic, other than as an abstraction. But is this what Einstein proceeds to do - isolate all the volumetric, Space-producing manifestations of energy? No. Instead, he proposes a different abstraction, one that describes the state of the relativistic Spacetime continuum by deformation potentials, or 'functions of space'. He seeks, in this manner, to dispose of the stationary Aether and of any notion of an absolute space. Yes, the Aether has physical properties, but these are (or would be) purely geometric and topological - that's what Einstein says.

Now, we are not saying that there is no physics to geometry or topology; no, that's hardly our point. But the real question is whether a geometry or a topology can be physical if they fail to obey energy considerations. Simply put, Einstein did not know how to extract Space as a concrete microfunction from the event *energy*, from the very variation of the Space-Time continuum. And why not? Because his concept of manifolds, of Space and Time, remained prisoner of a certain tradition of topology. He looks for the connections between Aether and Space, between Aether and Aether and Aether and Matter, but all he finds are axiomatic encodings which do not obey an energy description and which he must organize topologically.

So then, note - Einstein claims that Space is never physically empty, but he fails to state - by the positive - that Space is full of something, such as full of energy. His 'being full' concerns the physicality of Space, concerns the effects of the physical nature of Space. He does not step beyond this threshold. He does not move forward to encounter a Space that could be a pure function of latent energy - devoid of electric and electromagnetic events - and not merely or just a formal space; he does not realize how Space could be empty of electromagnetic fields and still be traversed or produced by the primary electric fields associated with the propagation of potential; nor does he realize how a gravitational field is composed of discrete particles

(gravitons) and has its own velocity for propagation of the gravitational potential. Underhandedly, all became ruled by the paradigm of electromagnetic energy: all energy will now be said to be electromagnetic and lightspeed to be an absolute limit. Gravitational waves travel at c, so does the inertial interaction, so does Light, so does the electrodynamic field. It is a senseless uniformity.

What is fundamentally new in the Aether of the General Theory of Relativity as opposed to the Aether of Lorentz consists in this, that the state of the former is at every place determined by connections with the Matter and the state of the Aether in neighbouring places, which are amenable to law in the form of differential equations; whereas the state of the Lorentzian Aether in the absence of electromagnetic fields is conditioned by nothing outside itself, and is everywhere the same.

Hence, Einstein settles for much less than one would have imagined him wanting to settle for. In essence, his only objection to Lorentz's Aether is that it only interacts with Matter to generate electromagnetic fields, but never with itself, by virtue of contiguity, and in the absence of those fields. Moreover, this conditioned and conditioning Aether of General Relativity also functions as something much more than Lorentz's Aether - it claims to explain both inertia and gravitation, but without once taking into account their energy basis.

The Aether of the General Theory of Relativity is transmuted conceptually into the Aether of Lorentz if we substitute constants for the functions of space which describe the former, disregarding the causes which condition its state. Thus we may also say, I think, that the Aether of the General Theory of Relativity is the outcome of the Lorentzian Aether, through 'relativation'.

'Functions of space', Einstein calls them - since space is treated independently from energy as an abstract space, and independently from Time - real Time or, if you will, universal Time. Time is precisely the manifold which has no reality in Relativity, and is reduced to (abstract) space in the mapping formulas for the Spacetime continuum. For Einstein confuses the nonisotropic and heterogenous nature of Space with an impossibility of synchronicity existing throughout the Aether - thus remaining prisoner of Lorentz's thought and the inheritance of classical physics. Blocked in this way, he could never proceed to realize that the properties of Space - no less than those of Time - are those of energy.

As to the part which the new Aether is to play in the physics of the future we are not yet clear. We know that it determines the metrical relations in the Spacetime continuum, e.g. the configurative possibilities of solid bodies as well as the gravitational fields; but we do not know whether it has an essential share in the structure of the electrical elementary particles constituting Matter.

True to his knowledge, Einstein admitted just how little he knew, and physics knows, about the fine structure of Matter. But he was deeply wrong in thinking that General Relativity truly knew how the metrics of the Space-Time continuum really vary - even for configurations of solid bodies - since this variation was not based strictly or correctly on energy considerations.

Nor do we know whether it is only in the proximity of ponderable masses that its structure differs essentially from that of the Lorentzian Aether; whether the geometry of spaces of cosmic extent is approximately Euclidean. But we can assert by reason of the relativistic equations of gravitation that there must be a departure from Euclidean relations, with spaces of cosmic order of magnitude, if there exists a positive mean density, no matter how small, of the Matter in the

universe. In this case the universe must of necessity be spatially unbounded and of finite magnitude, its magnitude being determined by the value of that mean density.

Lastly, and nearing the close of his address, Einstein makes a fundamental observation. For Aetherometry, there is little doubt that "spaces of cosmic order" - no less than the concrete microspaces of energy units - are not Euclidean, nor do they obey Euclidean relations. There are no straight lines in nature, and Euclidean space is a geometric concept of an abstract space, a concept amongst many of the abstract essence of space, not a physical concept of Space. However, from the non-Euclidean nature of the Space-Time continuum Einstein now takes a fundamentally aetherometric conclusion: that the totality of all spaces within the Space-Time continuum must be *unbounded and yet finite*. This is remarkably close to Aetherometry, with a small difference: we must qualify this "finite" with "at any moment in Time". Otherwise, it is physically meaningless, as it can only denote that the substance of Space is limited in abstract, that Space is conserved as such, that abstract Space is quantifiable in some absolute fashion by topology and the geometry of distances between points. Altogether different is the aetherometric qualification "at any moment in Time": for Space is indeed unbounded and thus has no outside, and is also indeed finite - but its total volume varies, is a variable, precisely because space is a property of energy and concrete spaces can superimpose with one another - which is exactly what happens when the massfree energy of a certain Aether manifestation becomes superimposed with a particle of Matter as its kinetic energy. Massfree Aether can superimpose with Matter and can superimpose with itself. Hence Space is finite, unbounded, but a variable, a variable in Time, because the totality of all spaces is the product of a perpetual energy flux. It is not Space that is conserved in an infinity of Time; what is conserved is energy.

If we consider the gravitational field and the electromagnetic field from the standpoint of the Aether hypothesis, we find a remarkable difference between the two. There can be no space nor any part of space without gravitational potentials; for these confer upon space its metrical qualities, without which it cannot be imagined at all. The existence of the gravitational field is inseparably bound up with the existence of space.

In the preceding, Einstein intuits the structure of the Aether lattice discovered by Aetherometry and extracted from its treatment of the universal force constant G [**4**]. Put simply, there is really no inertial motion - there is electric acceleration and gravitational acceleration, that's all. No system undergoes uniform translation, and moreover, even Space devoid of electromagnetic fields or ordinary Matter will present a gravitational field. But the existence of a gravitational field is not bound up with the existence of Space, not per se - the existence of a gravitational field emerges directly from the self-ordering properties of the Aether, as a property of the *Aether lattice* - but Space has a more primary function still, one that is already a property of massfree energy and exists aside from any consideration of this energy in the form of gravitons. For gravitons subtend Matter, even cosmological Matter, but it is energy that subtends Space, that produces it. At the end of the day, the gravitational field is no more bound up with Space than any other massfree field is, including the electric and the electromagnetic fields. And if it is true that the gravitational field provides structure to Space, or to a given region of Space, this is an energy structure that coexists with other energy structures in that same region of Space.

On the other hand a part of space may very well be imagined without an electromagnetic field; thus in contrast with the gravitational field, the electromagnetic field seems to be only secondarily linked to the Aether, the formal nature of the electromagnetic field being as yet in no way determined by that of gravitational Aether.

And one more fundamental intuition of Einstein's: that which is primarily linked to the Aether is the gravitational field, and not the electromagnetic field. Yet, once again, an intuition without encore, since Einstein remained unable to see how other fields, too, are also primarily linked to the Aether - such as the massfree electric field, or the pressure gradient 'field' of latent phase energy. At any rate, here is Einstein clearly stating, as Aetherometry maintains, that the Aether is not electromagnetic, and that the electromagnetic field is a secondary production.

From the present state of theory it looks as if the electromagnetic field, as opposed to the gravitational field, rests upon an entirely new formal *motif*, as though nature might just as well have endowed the gravitational Aether with fields of quite another type, for example, with fields of a scalar potential, instead of fields of the electromagnetic type.

Once again, Aetherometry would simply add that similar fields of scalar potential can be found at work in massfree electricity and latent energy.

Since according to our present conceptions the elementary particles of Matter are also, in their essence, nothing else than condensations of the electromagnetic field, our present view of the universe presents two realities which are completely separated from each other conceptually, although connected causally, namely, gravitational Aether and electromagnetic field, or as they might also be called space and Matter.

And, at last, we come to that cardinal error that bedeviled Einstein long past the 1920's: that Matter itself is a condensate of the electromagnetic field, such that its essence is not Aether per se but Light. Such is Einstein's appreciation of Jeans' relation: $E = mc^2$. The problem is that an equivalence between mass - or mass-energy, more properly - and electromagnetic energy only tells us that mass-energy can be converted into electromagnetic energy. But, unlike what is supposedly happening when, for example, an electron-positron pair is created from 'a gamma ray', creation of mass-energy is not the result of the materialization of Light. On the contrary, materialization of energy qua creation of mass-energy is the result of the secondary phase-superimposition of Dark Energy, specifically massfree latent energy. What is more, as we have shown aetherometrically, the structure of mass-energy itself is not electromagnetic, but electric. In the case of the electron, for example, we have shown the following to apply fully:

$$\mathbf{E = m_e c^2 = \lambda_e W_k W_x = e W_x}$$

Thus, the Jeans-Einstein equation offers only the electromagnetic equivalent of mass-energy, not the *electric fine-structure* of that mass-energy! Matter is a condensate of the Aether, and not of the electromagnetic field. Yet it plays a major role in establishing the electromagnetic field - not only because its states of motion generate blackbody photons, but also because mass-energy can be entirely converted into the electromagnetic energy of radiological photons.

Of course it would be a great advance if we could succeed in comprehending the gravitational field and the electromagnetic field together as one unified conformation. Then for the first time the epoch of theoretical physics founded by Faraday and Maxwell would reach a satisfactory conclusion. The contrast between Aether and Matter would fade away, and, through the General Theory of Relativity, the whole of physics would become a complete system of thought, like geometry, kinematics, and the theory of gravitation. An exceedingly ingenious attempt in this direction has been made by the mathematician H. Weyl; but I do not believe that his theory will hold its ground in relation to reality. Further, in contemplating the immediate future of theoretical physics we ought not unconditionally to reject the possibility that the facts comprised in the quantum theory may set bounds to the field theory beyond which it cannot pass.

In our view, the bounds would have to come not from quantum theory, but from an energy-based treatment of both field theory and quantum theory. Some sixteen years after this address, Einstein would be reminded of this reality - the inability of quantum theory to set such bounds - when a majority of physicists adopted the Copenhagen principle of complementarity.

Recapitulating, we may say that according to the General Theory of Relativity space is endowed with physical qualities; in this sense, therefore, there exists an Aether. According to the General Theory of Relativity space without Aether is unthinkable; for in such space there not only would be no propagation of light, but also no possibility of existence for standards of space and time (measuring-rods and clocks), nor therefore any space-time intervals in the physical sense. But this Aether may not be thought of as endowed with the quality characteristic of ponderable media, as consisting of parts which may be tracked through time. The idea of motion may not be applied to it.

To sum up our commentary: it is because Space is a concrete property of energy that it has physical properties which vary with the form of the energy manifestation. That is so for both Aether and Matter, since both are forms of energy manifestation, massfree and massbound. Space devoid of ordinary Matter is only composed of Aether qua massfree energy. Space cannot be thought of without energy, anymore than Space devoid of ordinary Matter can be thought of without massfree energy. The continuum of Space and Time is a continuum of energy, ultimately of massfree energy. There is, ultimately, no Space without Aether. And to this extent Aetherometry agrees with General Relativity. But there is also no Time without Aether, no universal Time, no synchronicity - because Space and Time are distinct multiplicities of the Aether, and because gravitational energy does not exhaust all the possibilities of massfree energy. Lastly, Matter or massbound energy is nothing other than trapped Aether, not trapped Light. Light is only produced when Matter loses its kinetic states or is dematerialized, annihilated. Light is a shallow river, a secondary manifestation of the interaction of Aether and Matter. But Light and Matter share the same frame of reference, at once electromagnetic and inertial, a photoinertial frame.

In this way, then, the reader may understand how the Gravitational Aether of Einstein and his General Theory of Relativity differs from the massfree Aether of Aetherometry, which is not simply gravitational.

NB - In Einstein's text, Einstein's emphases are in italics, ours in underlinings.

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