William Donahue, November 5, 2021

What would Kepler say to Einstein?

The more I think of this topic, the more appalled I am at my hubris in proposing it. "Really, Mr. Donahue (you might be thinking), "aren't you just using Kepler's name to throw out your own rash thoughts into an arena in which you have no business contending?"

As for the arena, I have no defense, other than that here at St. John's we routinely contend in contests where, by standards accepted elsewhere, we have no formal qualifications. We do it anyway, unapologetically. We do not expect to establish new truths, nor to overthrow established theories. But we do hope that in this rather mad undertaking we may gain for ourselves a little more understanding, both of the amazing universe we live in and the powerful thinkers and their remarkable insights into that universe.

In presuming to offer advice to Einstein (ostensibly in the persona of Kepler), I am on much shakier ground. The theme of this lecture sprang from a lecture I gave some years ago at Johns Hopkins, which had to do with Kepler's introduction of physical principles into astronomy. In the question period, I was asked what could be learned (if anything) from Kepler's views on what constitutes a good hypothesis. I replied that, more than merely accounting for phenomena, it would have to be based in physical reality. This occasioned much rolling of eyes, presumably at my extreme naïveté, which led me to ponder, in the ensuing years, what Kepler might have understood by "physical reality," and whether a similar mode of understanding might be applicable to more recent physical theory.

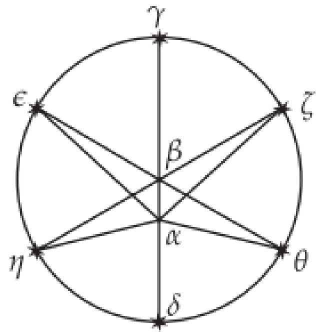
At length I thought about Einstein's replacement of Maxwell's "luminiferous ether" with a postulate asserting the constancy of the speed of light in all possible inertial frames of reference. This seemed to me a theoretical move about which Kepler would have been extremely skeptical. The idea of the ether, after all, was introduced into electromagnetic theory in order to provide a medium for electromagnetic waves, whose existence could be demonstrated. These waves were conceived as being similar to sound waves in air and other fluid media, and the idea of a wave in *nothing*, without any medium or substrate, was (I believe) calculated to raise objections from the community of physicists. And with them, I believe, would be Kepler, were he still around to express his views.

Now of course Kepler did not say anything about waves, so I must say first of all what criteria he used in evaluating a scientific hypothesis, and why I think he would have raised an objection to Einstein's rejection of the ether.

One of the best examples of Kepler's thinking about the physical reality behind the apparent motion of the planets is found right near the beginning of *Astronomia Nova,* in Chapter 2. This chapter is a deliberate reprise of Book I Chapter 3 of Ptolemy's *Almagest,* but Kepler takes the argument a giant step farther, asking how each of the two kinds of hypotheses (epicyclic and eccentric) could be understood to function in physical reality. And for Kepler, the limits of physical reality are very broad, but are also clear and definite. So here is where we have to begin.

Kepler takes it as demonstrated that there are no real, rigid epicycles and deferent circles or spheres in the heavens. The question, then, is how the moving power (supposed for the moment to reside in the planet) could make the planet move in a circle. Like Ptolemy, Kepler considered both the eccentric hypothesis and the concentric-with-epicycle hypothesis; in the interest of time, we will consider only the former.

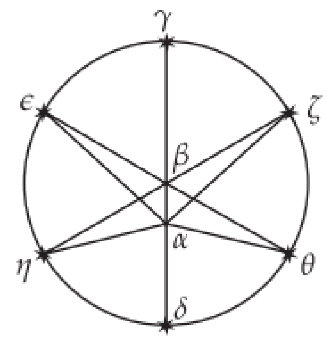
This power, whatever it is, would have two jobs: it would have to be strong enough to move the body of the planet, and it would have to know where to move it. This would require knowledge or perception of the circular path in the unmarked aethereal air—a function of intelligence and not physics.



Now a circle, Kepler says, even for God, is nothing but equality of distance from some point. Citing Avicenna, he says that the planet will either have to "imagine for itself the center of its orb and its distance from it," or use some other property of a circle to establish its distance and direction. Here's the example Kepler gives. The planet's assignment will be to move on the path γεδ, with center β (not occupied by any body or perceptible mark). This center is fixed in position with respect to point α, which is occupied by a body. To make this motion possible, the planetary mover might be endowed with some means of perceiving the angular size of the body α, as it should appear, in succession, at γ, ε, η, δ, continually adjusting its distance from α while moving with uniform speed on the resulting circle. Somehow, it will have to match continually the distances γα, εα, ηα, δα, and so on (calculated by observing the apparent size of the body at α), with the angles γαε, γαη, γαδ, respectively. It will also have to know the direction of the line of apsides, αγ, in the sphere of the stars. As Kepler says, "The planet's mover will thus be occupied with many things at once," his implication being that this arrangement makes no sense.

"To escape this conclusion," he continues, "one must assert that the planet pays attention to the point β, entirely empty of any body or real quality, and maintains equal distances from that point."

"Body or real quality": that is the kind of thing that Kepler was looking for. It would have to be perceptible, somehow, even if it were not the same as objects that we interact with every day. Objects of pure mathematics, such as points and lines, would not do. Beyond that, Kepler was extraordinarily open to analogies, both mechanical and living. Earlier in the chapter, he considers at length the operations of muscles in the human body, and concludes that animal locomotion would not be a good model for planetary motion; nonetheless, he is very much open to a role for minds in the heavens.



In passing, it is fascinating to note that Newton, too, found that the supposedly "natural" circular motion could not be produced by central forces alone. The moving body would have to take into account, in addition to its velocity and its distance from the center of force, the chord from its present position through the center to the opposite side of the circle. Thus it would have to know where it would be on the other side of its orbit!

We are now prepared to imagine what Kepler might think while reading Einstein's world-changing paper "On the Electrodynamics of Moving Bodies." He would certainly want to know what this "electrodynamics" is. Maybe the best explanation would be to display the two experimental demonstrations that Einstein describes, which (I hope) are now familiar to all seniors.

[show two videos, one with a hand moving a magnet through a coil of wire, the other with a hand moving the coil with the magnet fixed.]

Kepler might be surprised to see the magnetic needle wiggle, whether the magnet moves inside the coil of wire or the coil moves along the magnet. He might be more surprised to learn that, despite the identical effects of the motion upon the magnetic needle, the theory requires that there be two very different accounts of what is happening. Here is Einstein's description:

> "If the magnet is in *motion* and the conductor at *rest*, there arises in the neighborhood of the magnet an electric field with a certain definite energy, producing a current at the places where parts of the conductor are are situated. But if the magnet is *stationary* and the conductor in *motion*, *no* electric field arises in the neighborhood of the magnet. In the conductor, however, we find an electromotive force, to which in itself there is no corresponding energy, but which gives rise—assuming equality of relative motion in the two cases discussed—to electric currents of the same path and intensity as those produced by the electric forces in the former case." [emphasis supplied]
>
> (This is clearly shown by the deflection of the needle in the two cases.)

Kepler would, I think, be reminded of the physical difference between planetary motion as conceived by the geocentrists and the motion as seen by the heliocentrists. The *phenomena* as observed by the astronomers would be the same in both cases, but the *physical reality* would be radically different. I imagine he would say, "Well, two contradictory accounts cannot both be true, so one of the descriptions must be the correct one."

Einstein, however, went off in a completely different direction. Ignoring conventional ideas of space and time in Newtonian physics, he adopted two principles, which he initially raised as conjectures, but immediately (in his own words) "raised to the status of postulates."

> 1. The same laws of electrodynamics and optics will be valid for all frames of reference for which the equations of mechanics hold good.
>
> 2. Light is always propagated in empty space with a definite velocity *c* which is independent of the state of motion of the emitting body.

A "postulate," we should recall, is how we usually translate the Greek Ἀιτήμα, meaning "demand, request." It is a statement that the author requests us to accept as true, without proof, as a basis for the demonstrations that will follow. Einstein states that he will use these postulates to attain “a simple and consistent theory of the electrodynamics of moving bodies based on Maxwell’s theory for stationary bodies.” In other words, he proposes to fix the inconsistency between the theoretical accounts of electromagnetic induction, noted above, not by adopting one or the other account as “true,” but by a radical reformation of the *foundations* of all of physics, by adding these two postulates to Newton’s three “Axioms, or Laws of Motion.”

Now I do not think that Kepler would be troubled, in principle, with the idea of a radical reform of physics. But I do think he would be troubled by Einstein’s next sentence. Einstein wrote, “The introduction of a ‘luminiferous ether’ will prove to be superfluous inasmuch as the view here to be developed will not require an ‘absolutely stationary space’ provided with special properties.” Since Kepler believed that God had created a finite, spherical universe with the sun at its center, he clearly was an advocate of a stationary space with special properties, such as privileged places. But aside from this, I will argue that, theology aside, Kepler would have philosophical or methodological objections to abandoning the Maxwellian ether. To do this, I will have to make an excursion into the considerations that led Maxwell and other physicists of the nineteenth century to espouse the ancient idea of an ethereal medium filling all space.

The excursion I propose will lead us into some rather elementary physical considerations. These may be the sort of thing that Einstein would think of as “superfluous,” but this is exactly the kind of inquiry that Kepler enjoyed. So let us invite him to join us in considering the “simple” pendulum.

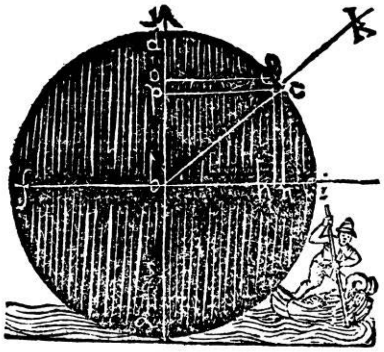
[video of pendulum]

[video of two loosely linked pendulums]

[video of a number of loosely linked pendulums]

[video of Bell wave machine, first with all but one bar clamped, then with the clamp removed so as to create a wave]

Kepler was very good at constructing mathematical models of physical actions, but (as we saw in *Astronomia Nova*) he wanted more from a sound physical explanation. In several places in *Astronomia Nova* he set out a three-leveled structure: the observational evidence, geometrical modeling of the observations, and a physical account that could underlie the geometry. As for what could serve as a "physical account," Kepler was open to a very wide range of examples: animal joints and muscles, magnetism, whirlpools and other examples of water flow (such as Heron's fountain), amusement park rides, oars and paddles, and so on. He seems to have sought examples that would be generally acknowledged as physically real and that could be understood as constituting an analogue to a phenomenon that is felt to be in need of explanation. In proposing such examples, he was often not claiming that the analogy provided a full and adequate account of the phenomenon, only that the physical reality might be somewhat like the example. Sometimes he combined two different analogies in a single diagram, as here (from *Astronomia Nova* Chapter 59), where a magnetic planet (the big black circle) with a vertical axis (note the arrowhead at the top) is alternately attracted and repelled by the sun, but is also being propelled by a boatman with a pole (or perhaps an oar). He also candidly admits the provisional or conjectural nature of some of his analogies: for example, in Ch. 57 he writes, "I am satisfied if this magnetic example demonstrates the general possibility of the proposed mechanism.



Concerning the details, however, I have doubts...There may be absolutely no material, magnetic faculty that can accomplish the tasks entrusted to the planets individually…” His point is, that wherever possible, it is preferable to invoke a physical force or power such as magnetism or weight, but if all else fails, it is permissible to invoke mental or animate powers.

So let’s think about what Kepler might hope for as a generalized physical metaphor or underpinning for wave phenomena. To help us, I’d like to bring back the Bell wave machine.

[Bell video]

We may think of the machine as an assembly of linked pendulums. Each crossbar is attached to a longitudinal torsion bar that runs the length of the machine. If the crossbar at the end is displaced and released while the bar next to it is clamped in place, it oscillates while all the other crossbars remain at rest.

[video with just one bar moving]

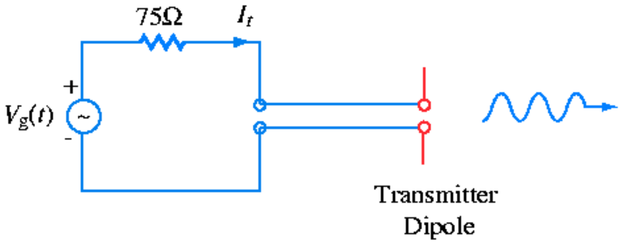
It is acting as a torsional pendulum. When its displacement is at its maximum, the twisting force is also maximum, and the bar, when released, moves in the direction of the force, towards its rest position. But when it gets to its rest position, it has acquired some speed, which carries it past the rest position to a new maximum displacement.

If we remove the clamp from the next crossbar, the motion of the first bar twists the torsion bar, which then imparts that twist to the next crossbar, which in turn adds a twist to the torsion bar, and thus the twisting motion is passed on. It’s much like those pendulums we saw earlier, that were connected by springs.

So it appears that in order to have a wave in some medium, two things are needed.

1. Individual places in the medium have to be able to move like pendulums: when given an initial push, they will depart from their position, but they then experience a restorative force in the medium that pushes back towards whence they came;

2. The pendulums have to be linked so that the swinging of each of them is communicated to neighboring pendulums. When they are tightly linked, the wave move quickly through them; when loosely linked (as the pendulums were), the motion is communicated more slowly.



This can be applied to electromagnetic waves in a general way quite directly. Consider this simple assembly of two collinear pieces of metal (called a "dipole"), colored red, connected to the output of a device (the transmitter) that makes electricity slosh back and forth between the two sides of the dipole. The transmitter/dipole assembly is our initiating pendulum: the natural tendency of the electricity is to create an equality of tension or "potential" between the two sides of the dipole; the transmitter provides the pushes that keep the electricity oscillating. What happens, as we know from Faraday, is that the electric and magnetic forces generated by this assembly ripple out through the surrounding space. Electric tension builds up in space, and as the tension is released by the restoring force of the medium, this release constitutes an electric current, which generates a magnetic force, which grows and decreases in a similar way, generating an electric displacement current, and so on. This action continues, and constitutes what we call a "radio wave." And there is strong evidence that light, too, is just such a wave.

So the wave metaphor, built up out of linked motions that act like pendulums, evidently applies to electricity, magnetism, and light too, in a direct and comprehensible way. In the face of such evidence, Kepler might say, is it not a retrograde step to dismiss as “superfluous” the medium in which the actions foundational to the observed phenomena take place? Isn’t adopting the “postulate” that the speed of light in a vacuum is constant too much like postulating (as astronomers had done for thousands of years) that all celestial bodies move with uniform circular motion?

This, then, is what I think Kepler would say to Einstein. And I could stop here, but in all fairness, we need to let Einstein respond.

I think Einstein would point out two problems, one cosmic in scale and one inherent in electromagnetic theory as it was then formulated.

The first is related to the ether itself: are we moving through it, or is it moving along with us? If we are moving through it, then waves would seem to us to be moving faster in some directions and slower in others. But when we measure the speed of light, it seems to be pretty much the same in all directions. It gets worse: the speed of electromagnetic waves, as deduced from Maxwell’s equations, is determined by the ratio of the two fundamental electrical and magnetic constants. These are the physical constants that seem, both conceptually and experimentally, to be independent of coordinate systems, and that determine the “springiness” of the medium. In junior lab, every spring, we do a lovely experiment that gives us a number for this ratio, and our number (perhaps surprisingly) is pretty close to what the textbooks say it should be. And further, when (in a second beautiful experiment) we measure the speed of light directly (using a tape measure and a tuning fork), the number we get is not too far from the ratio in the previous experiment. So we are left with a dilemma: either the fundamental electromagnetic constants are somehow coordinate-system dependent so that they match the measured motion of our coordinate system through the ether, or there is a preferred coordinate system for the entire universe in which we happen to be absolutely at rest. It's hard to imagine what the first horn of the dilemma even means, while the second horn basically throws out all cosmological thinking since Copernicus. We can call this problem the "ether wind" problem.

The other thing Einstein would say is that in his view, this whole dilemma associated with the ether is just a side issue: his concern, which he thinks was a much more fundamental problem, was the asymmetry in the way Maxwellian electrodynamics applies to magnets and wires. As Einstein put it, in the passage quoted earlier in this lecture,

> "If the magnet is in motion and the conductor is at rest, there arises in the neighborhood of the magnet an electric field with a certain definite energy, producing a current at the places where parts of the conductor are situated. But if the magnet is stationary and the conductor in motion, no electric field arises in the neighborhood of the magnet. In the conductor, however, we find an electromotive force, to which in itself there is no corresponding energy, but which gives rise—assuming equality of relative motion in the two cases discussed—to electric currents of the same path and intensity as those produced by the electric forces in the former case."

Restating this in a slightly different way, if you have an observer who sees the magnet moving through the coil of wire, she sees an electric field in the space surrounding the magnet, and this field embodies a definite amount of energy. Another observer, moving uniformly along with the magnet, will see no electric field, and the same space will now be devoid of energy. But energy is a conserved entity. So we have a theory that has lost what later physicists have called "local reality”: for one observer some real thing is there which *according to the laws of physics* is not there for the other observer. Thus, the whole idea of objective reality has broken down, which, you may imagine, is a big no-no for a physical theory.

So Einstein’s response is to adopt the two “postulates,” mentioned earlier, by which he will solve both the ether wind problem and the objective reality problem. His claim is that abandoning the idea of a physically real medium in which electromagnetic waves occur is a price worth paying for saving the claim of physics to represent objective reality.

So, Kepler, what might you have had to say in response to Einstein’s powerful reply?

It is clear from our brief look at *Astronomia Nova* Ch. 2, and from many other places in the book, that Kepler believed it was wrong to allow a physically unsupported postulate (uniform circular motion) to overrule principles, even if they are provisional or conjectural, that are supported by physical arguments. As he put it, we need “a body or real quality” as a foundation. Although he was open to a wide range of examples and analogies that would constitute “real qualities,” a simple rule lacking such support, such as the constancy of the speed of light, would not do. Although Kepler would have acknowledged it as a clever and ingenious solution, it would remind him too much of the many astronomers of his day who rejected his “celestial physics” (a term featured prominently on the title page of *Astronomia Nova*) and reverted to the circular tracks and angelic movers of the old astronomy.

What would have to be done instead, Kepler would say, would be to *solve the ether wind problem and the local non-reality problem without abandoning the physical* *basis of electromagnetic radiation*. This would surely be a difficult task. But would it be more difficult than establishing a sound physical basis for planetary motion?

I'll finish this lecture by saying a few things in support of Kepler's advice. Not that I consider Kepler's position is in need of support—it seems to me one of the really deep questions—but to show that, despite what seems to be the unanimous acceptance of Einstein's two postulates, there has been, and continues to be, a quiet but respectable undercurrent among physicists, a willingness to wonder whether despite the remarkable success of Einstein's relativity theory, its unsupported second postulate might turn out to have been a mistake.

The first direct attempt to determine a possible motion of the earth through the ether was carried out in 1881 by A. A. Michelson, in Potsdam, Germany. Michelson nonetheless noted that the problem had already been approached by Stokes (in 1846) and later by Maxwell (1878). The more famous Michelson-Morley experiment, which used a much larger instrument, followed in 1887. These purely experimental results, which showed no measurable motion, set a problem for the theorists to solve.

The approach that appeared most promising at first was that some of the ether was being dragged along by the earth; however, no one succeeded in demonstrating such a phenomenon. A competing account was suggested by Oliver Heaviside's conclusion, on the basis of Maxwell's electromagnetic theory, that electromagnetic fields contracted along the direction of their motion. In 1895, H. A. Lorentz published an article in which he proposed that, like electromagnetism, the forces that hold the particles of material bodies together also contract in the direction of motion. He writes,

> “Thus one would have to imagine that the motion of a solid body (such as a brass rod or the stone disc employed in the later experiments) through the resting ether exerts upon the dimensions of that body an influence which varies according to the orientation of the body with respect to the direction of motion. …
>
> “Surprising as this hypothesis may appear at first sight, yet we shall have to admit that it is by no means far fetched, as soon as we assume that molecular forces are also transmitted through the ether, like the electric and magnetic forces of which we are able at the present time to make this assertion definitely.”

In 1904 (the year preceding Einstein’s Special Relativity article), Lorentz published a more thorough treatment of the same basic idea. In the interim, Poincaré had argued that electromagnetic forces alone were insufficient to produce Lorentz’s contraction, and added an additional hypothetical force. However, as Lorentz notes, Poincaré also objected to this piecemeal approach. Lorentz writes:

> “Poincaré has objected to the existing theory of electric and optical phenomena in moving bodies that, in order to explain Michelson’s negative result, the introduction of a new hypothesis has been required, and that the same necessity may occur each time new facts will be brought to light.”

Lorentz believed that by “starting from the fundamental equations of the theory of electrons,” he could “treat the subject with a better result.” The article that followed is a tour-de-force of Maxwellian analysis, packed with equations dealing with such matters as the electromagnetic inertia of electrons.

At this point, Lorentz’s fundamental revision brought his theory, which avoided Einstein’s second postulate, into agreement with Einstein, as far as the observations were concerned. But by a strange turn of events, a series of experiments by Walter Kaufmann (involving the mass of high-speed electrons rather than motion through the ether) appeared to show that the Einstein/Lorentz predictions were wrong, and that rival theories of Max Abraham and Alfred Bucherer produced more accurate results. Lorentz conceded that Bucherer's theory was "decidedly unfavorable to the idea of a contraction, such as I attempted to work out." Einstein, on the other hand, acknowledged that the Abraham and Bucherer theories fit the data better than his own, but wrote, "they have a small probability of being correct since they produce complicated expressions for the mass of a moving electron." In other words, theoretical simplicity trumps agreement with the data!

But now Planck entered the fray, with a meta-analysis of Kaufmann's numbers, which tipped the balance back in favor of Einstein and Lorentz. And in 1914, refined experiments by Günther Neumann (using Kaufmann's own equipment with some modifications) appeared to favor Einstein decisively. The curious result of this was that, even though Einstein's and Lorentz's theories were essentially in agreement in most of their predictions, Einstein's ether-free approach came to be viewed as the victor.

Nevertheless, attempts to find an "ether wind" continued. The most extensive work was by Dayton Miller, a prominent American physicist who was president of the American Physical Society in 1926. His measurements extended over nine years and, by one account, comprised over five million individual measurements. His primary aim was to show a difference between the ether drift at low elevations (essentially none) and at the summit of Mt. Wilson. He claimed to have found that the solar system is moving towards the constellation Dorado through the ether at a speed of 227 km/s, a result that was similar to independent measurements by the French astronomer Ernest Esclangon and the Swiss astronomer Leopold Courvoisier. These results have been questioned on various grounds, but were well-received at the time and have never been adequately repeated, according to one scholar whom I know personally and whose work I respect. It appears that the remarkable success of both the special and general theories of relativity have made a search for ether-drift an unattractive career move.

However, questions have more recently crept in from an unexpected source: quantum mechanics. Physicist John Bell, in 1964, came up with a purely mathematical theorem that established certain numerical limits to the relatedness of states of certain particles (in this case, polarizations of so-called "entangled photons"). The assumptions upon which the theorem was based were, first, that the particles involved really and actually possess the properties involved (the criterion of "reality"), and second, that communication among the particles cannot occur at speeds faster than light. Naturally, this set a challenge for experimenters: violate Bell's theorem! The definitive experiment, by Alain Aspect, came along in 1982. It violated the conditions of Bell's theorem, while remaining entirely consistent with quantum mechanics. In practical terms, this meant that one or both of the assumptions that Bell made would have to be abandoned or modified. Physics would have to give up the idea of local reality, or of what Einstein called "spooky action at a distance," or perhaps both.

One is reminded of what Kepler wrote in *Astronomia Nova* when he showed that the classically formulated hypothesis of Chapter 16 is inconsistent with the Tychonic observations. He wrote,

> Therefore, something among those things we had assumed must be false. But what was assumed was: that the orbit upon which the planet moves is a perfect circle; and that there exists some unique point on the line of apsides

> at a fixed and constant distance from the center of the eccentric about which point Mars describes equal angles in equal times. Therefore, of these, one or the other or perhaps both are false, for the observations used are not false.

So, in light of the Aspect experiment, what gets thrown out? A variety of solutions have been proposed, but I will conclude this lecture with what John Bell himself said, in a discussion with BBC producer J. R. Brown and physicist P. C. W. Davies.

Question:

Bell's inequality is, as I understand it, rooted in two assumptions: the first is what we might call objective reality – the reality of the external world, independent of our observations; the second is locality, or non-separability, or no faster-than-light signaling. Now, Aspect's experiment appears to indicate that one of these two has to go. Which of the two would you like to hang on to?

Bell:

Well, you see, I don't really know. For me it's not something where I have a solution to sell! For me it's a dilemma. I think it's a deep dilemma, and the resolution of it will not be trivial; it will require a substantial change in the way we look at things. But I *would* say that the cheapest resolution is something like going back to relativity as it was before Einstein, when people like Lorentz and Poincaré thought that there was an aether—a preferred frame of reference—but that our measuring instruments were distorted by motion in such a way that we could not detect motion through the aether. Now, in that way you can imagine that there is a preferred frame of reference, and in this preferred frame of reference things do go faster than light. But then in other frames of reference when they seem to go not only faster than light but backwards in time, that is an optical illusion.

Question:

Well, that seems a very revolutionary approach!

Bell:

Revolutionary or reactionary, make your choice. Behind the apparent Lorentz invariance of the phenomena, there is a deeper level which is not Lorentz invariant.

Question:

Of course the theory of relativity has a tremendous amount of experimental support, and it's hard to imagine that we can actually go back to a pre-Einstein position without contradicting some of this experimental support. Do you think it's actually possible?

Bell:

Well, what is not sufficiently emphasized in textbooks, in my opinion, is that the pre-Einstein position of Lorentz and Poincaré, Larmor and Fitzgerald was perfectly coherent, and is not inconsistent with relativity theory. The idea that there is an aether, and these Fitzgerald contractions and Larmor dilations occur, and that as a result the instruments do not detect motion through the aether—*that is a perfectly coherent point of view.*

Let me finish by briefly summarizing the main points of this lecture.

Kepler strove mightily throughout his life to oppose the prevalent idea that astronomy must be founded on hypotheses, and that the fundamental and indispensable hypothesis is the principle of regular, uniform circular motion of all heavenly bodies. He proposed instead that all attempts to understand the cosmos must be founded in some way upon physical reality. As to what constitutes physical reality, we must use familiar examples to try to understand what is less accessible to us, and we may be led to consider accounts or examples that may at first seem far-fetched. But it is a mistake to limit the range of possible explanations within the boundaries of arbitrary postulates. This is what I believe is the advice he would most want to give Einstein. And this is advice that, despite the rolling of eyes at Johns Hopkins, may retain a degree of cogency today.