What If Light Doesn't Exist?

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In our article (When Fields Are Not Degrees of Freedom), Vera Hartenstein and I show that the world of classical electromagnetism might differ radically from the one we see in physics textbooks and experience day-to-day. First, light may not exist; second, the laws of electromagnetism are either incomplete or completely different; and, third, the mathematics needed to make exact calculations with these novel laws is in early development and not part of the general mathematics curriculum at colleges and universities.

How did we arrive at such a revision of electromagnetism? We mathematically analysed what is called an initial-value problem. Standard physical laws, like Newton's second law, have the structure of an initial-value problem. And if laws do not have this structure—as the Einstein field equations in general relativity do not—physicists try to re-cast the physical situation as an initial-value problem. So what is an initial-value problem and why is it so prominent in physics?

Let's look at Newton's second law, which says that the acceleration of a body at one time equals the force exerted on the body (divided by the mass of the body). If we specify all the physical facts of a system at a certain time, the law tells how that system will behave in the future. Solely by specifying what the state of the world is at one moment in time (the initial time), a solution to this initial-value problem gives us the whole future (and also the entire past) of the world.

For example, if I want to calculate how exactly an apple that I release from my hand will fall to the ground, I need to know the initial location of the apple, the initial velocity of the apple, the mass of the Earth, and the distance of the apple from the Earth. We are normally free to choose the initial state of the physical system: I can throw the apple into the air, or imagine that I'm on the moon where gravity is much weaker, and Newton's law will tell me what the apple will do.

Physicists are familiar with these kinds of problems and have developed efficient mathematical machinery to solve them. Philosophers too are implicitly familiar with initial-value problems, because the three major theories of laws discussed today—Humeanism, primitivism, and dispositionalism—usually presuppose that laws determine the succession of events over time. (Only recently have philosophers opened the door to a more general approach to laws of nature; see, for example, Adlam [2022]; Chen and Goldstein [2022].) So why is it that this freedom to choose initial conditions becomes so problematic when we turn to electromagnetism?

In our article, we looked at the following situation: Take one charge at a particular time and choose a particular field surrounding that charge. What will happen to the charge and field? In our previous example of the falling apple, we had complete freedom to choose our initial position, velocity, and so on. Here, we face constraints: the charge and the field are not entirely independent of one another. For example, the (standard) laws of electromagnetism tell us that the charge has to be located where the field has sources and sinks. The simplest field is the one that is associated with one charge at rest. This field, called the Coulomb field, looks like a star or a sea urchin, and the charge sits exactly in the middle, where the field is most highly concentrated.

Now imagine that we give the charge some initial kick, so that it has some initial velocity, and we observe what happens. This is not forbidden by the laws of electromagnetism, but it will get us into trouble. By giving the charge a non-zero velocity and imposing the Coulomb field from the beginning, the charge will radiate very strong electromagnetic waves. More precisely, we can show mathematically that the field emitted by the charge will yield discontinuous changes with respect to the surrounding field (the precise mathematical calculations have been published in Deckert and Hartenstein [2016]; Hartenstein [2018]).

If another charge hits this type of radiation—a collision akin to hitting a brick wall with a car—this charge will bounce back, radiating strong electromagnetic waves as it does so. At least, this is what is predicted by the mathematics. The problem lies with the empirical evidence: we do not observe this strong radiation, nor do we observe these rebounding charges. It turns out that our world is not one where a charge surrounded by the standard Coulomb field has any non-zero velocity. That is, contrary to what seems to be allowed by classical electromagnetism, a charge in a Coulomb field cannot move.

How should we respond to this, and what are the philosophical consequences? First, we may take a conservative approach. We might add further laws to classical electromagnetism to accommodate the observation that a charge cannot move while surrounded by the

Coulomb field. This would mean that the theory of classical electromagnetism as taught throughout the world and in all the standard textbooks is incomplete.

Second, we may take a more radical approach and question the existence of the charges or the electromagnetic field. We showed that the charge and the field are much more connected than originally thought. Once we fix the field, the location and motion of the charge is fixed too—for example, it is at rest in the centre of the Coulomb field. Following this line of thought, we can argue that charges do not exist as separate objects from the field. We might then discard charges and claim that all that exists in space and time is the electromagnetic field.

In our article, however, we did not explore this path. Instead, we proposed and worked out another possible radical ontology in which charges, but not electromagnetic fields, exist. For this to be the case, one would require that charges influence one another directly over space and time. An accelerating charge would no longer send out an electromagnetic wave that affects the motion of another charge; instead, no further physical objects mediate the influence between two charges. In order to be consistent with the predictions of classical electrodynamics, these direct interactions between charges need to be delayed—it takes some time for one charge to feel the influence of another, as if light was traveling between them.

It is this delay that forces us to revise our received view of laws of nature and the mathematics that is needed to formally handle these laws. In the received view, the laws successively generate the future from the complete physical description at one time. If the electromagnetic field is no longer there, the complete physical description of the state of all the charges at one time does not uniquely determine the future. Instead, one needs to look into the past of every charge to find out whether there are other charges that directly influence it.

More precisely, for every charge we need to know a bit of its history—a bit of its past trajectory—to generate the future trajectories for all charges. Metaphorically speaking, we need to replace ‘horizontal initial conditions’ at one particular time, as required in the received view, with ‘vertical initial conditions’ that specify what charges did in the past. Then, the future is generated not through a succession of physical facts at instantaneous times—as movies proceed, for example—but rather through the complex, direct, delayed interactions between the physical bodies in the world. Therefore, philosophers need to revise how they think about laws of nature, and mathematicians need to develop tools to handle this structure of physical laws. The basic laws of motion in this picture are no longer ordinary differential equations, like Newton’s second law, but delay-differential equations, which are rarely studied by physicists and mathematicians.

It is this second approach that evolves from our analysis of the initial-value problem and makes us feel as though we are in the Matrix. Electromagnetic waves such as light may not exist, physical laws have a novel structure, and the mathematics that we normally use is unable to handle these new laws. Exploring this exciting path will undoubtedly give rise to all manner of novel ideas across mathematics, physics, and philosophy.

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