6 Electrodynamics

Einstein's 1905 paper, commonly regarded as the document which gave birth to the theory of relativity, has the title *On the Electrodynamics of Moving Bodies*. When the paper was published, the title did not attract any attention. In retrospect, however, it looks highly incongruous because *the title of Einstein's paper cannot be regarded as exactly or even largely representative of its thesis* (Keswani). The paper consists of a short introduction, a *kinematical part* and an *electrodynamical part*. The emphasis appears to be on electrodynamics, and the purpose of the kinematics is to serve as a theoretical framework. Einstein says that *the theory to be developed is based—like all electrodynamics—on the kinematics of the rigid body*, and then proceeds to show how his particular set of kinematic ideas can be applied to Maxwell's equations and some other randomly selected phenomena from electricity and optics.

Within two years after the publication of the paper the electrodynamical considerations dropped completely out of sight as can be seen in Einstein's contribution to an annual review in 1907 under the title *On the Principle of Relativity and the Conclusions Drawn from It*. Only the kinematical part remained and gradually transformed itself into the special theory of relativity. However, the origin and nature of Einstein's theory cannot be properly understood without an examination of its relationship with electrodynamics, and this means with Maxwell's theory of electromagnetism. Einstein's theory was conceived on the basis of Maxwell's equations, and the Michelson-Morley experiment, and the idea is still kept alive that electrodynamics is a branch of physics in which relativity has proved its validity.

The introductory section of the 1905 paper commences with the words: *It is known that Maxwell's electrodynamics—as usually understood at the present time—when applied to moving bodies, leads to asymmetries which do not appear to be inherent in the phenomena*. Einstein's point of departure is Maxwell's theory. He is concerned with *asymmetries* in it which are not in accordance with experience, and it is for the specific purpose of eliminating these assumed *asymmetries* that he proposes his theory. Einstein's complaint derives from the historically separate development of electricity and magnetism leading to the discoveries of Oersted and Faraday. Oersted observed that an electric current deflects a magnetic needle, and Faraday that a rotating magnet induces an electric current. In other words, electric currents produce magnetic effects and magnets produce electric currents. Although Maxwell combined electricity and magnetism in his theory, he retained the conceptual separation between electric and magnetic components because it made sense in physical terms. What Einstein is criticising is this conceptual separation which prevents the complete reciprocity of the effects from being properly appreciated. He thinks that the fault should be rectified by changing the mathematical formalism. He maintains that his method is mathematically simpler, although his conception of simplicity does not lead to any better understanding of electromagnetic processes. In fact, Einstein's formulation of the electromagnetic equations is more difficult than Maxwell's and has no demonstrable advantages whatsoever. Physicists could hardly consider the separate study of electric and magnetic phenomena as a fault because these phenomena are separate in nature and there is an eminently practical reason to leave them apart. Yet some relativists assert that Einstein *noted a contradiction in contemporary scientific beliefs apparent for years but conveniently ignored* (Clark). It is wrong to say that there was a *contradiction in Faraday's law of induction* (Clark). Faraday's law was not incompatible with Oersted's discovery and, in any case, Maxwell indicated how the two threads hung together. Einstein's problem was a non-problem, but it served as one of the two starting points for the special theory, the other being the Michelson-Morley experiment.

Between 1864 and 1873 Maxwell, after studying Faraday's work and other developments in electricity and magnetism, proposed a mechanical model of the mutual interaction of electrical and magnetic phenomena and then, using this model as a basis, expressed the interaction in mathematical equations. Maxwell's theory not only combined electrical and magnetic phenomena and established the concept of the electromagnetic field, but also predicted the existence of electromagnetic waves and opened the way for other developments in modern physics. Faraday had discovered that a moving magnet produces an electric current in a conductor in its vicinity. Maxwell's model indicated that in the absence of a conductor a displacement, signifying a current, occurs in the medium surrounding the magnet. The model also indicated that a displacement, in turn, gives rise to a magnetic effect. This corresponds, basically, to Oersted's discovery. As it was difficult to imagine a displacement in empty space, Maxwell supported the hypothesis that the medium surrounding magnets and conductors, and space in general, was filled with a quasi-mechanical substance of very low density and at the same time very high elasticity. This substance was referred to as aether and had a definite purpose in Maxwell's model although physical evidence of its existence was lacking. Maxwell's mechanical model is now forgotten or, if it is mentioned, considered to be crude and childish. But the fact is that he derived a series of mathematical equations from his model which summarised concisely and effectively the fundamental laws of electricity and magnetism. Field intensity vectors specify what is happening electromagnetically at every point in space in relation to conductors and magnets.

Maxwell used the concept of the electromagnetic field, and it signified for him something physically real. His first paper, read in 1864 to the Royal Society, had the title *On a Dynamical Theory of the Electromagnetic Field.* It was one of Maxwell's great services to physics to focus attention on the thought that the medium surrounding magnets and conductors is the seat of electromagnetic processes and that it transmits energy which produces effects in distant bodies. Although himself a mathematician by training, Maxwell criticised other mathematicians. He wrote in 1873: *Faraday saw lines of force traversing all space where the mathematicians saw centres of force attracting at a distance. Faraday sought the seat of the phenomena in real actions going on in the medium; they were satisfied that they had found it in a power of action at a distance.* Of course, the use of such concepts as aether or field did not explain the nature of the underlying electromagnetic processes in space, and it is true to say that these concepts covered up the lack of knowledge as to how action at a distance is actually effected. But Maxwell's field represented nevertheless a very useful intermediate solution of the problem.

Maxwell was not satisfied to propose a model of electromagnetic interaction and to formulate a mathematical expression of it. He considered also some important consequences. What would happen, for instance, if an electric current is made to oscillate in a piece of wire? The oscillations will produce fluctuations of the electromagnetic field in the vicinity of the wire and these fluctuations will spread like waves in all directions. Maxwell thus predicted the existence of disturbances of the aether which would enable the transmission of energy in the form of electromagnetic radiation. And it was also a consequence of his theory that the speed of electromagnetic wave propagation would be equal to the velocity of light. These predictions were confirmed by Hertz in 1887-1888. It was also established that light was electromagnetic radiation within a certain frequency range.

Hertz, although predominantly an experimentalist and practical physicist, expressed some theoretical views in which he separated Maxwell's non-mathematical model from his equations and urged his colleagues to discard the former completely. By itself, this was not necessarily an action of great importance. But concurrently with dropping Maxwell's mechanical model Hertz rejected also the use of such models in general as a means of explanation in physics and signified his preference for the mathematical expression of relationships between physical phenomena. Historically, this inaugurated a change in the further progress of physics. In particular, it meant that electromagnetic phenomena severed their ties with mechanics and became a separate branch of physics. In general, it meant that the path was cleared for the supremacy of mathematics in physics. The advance of electromagnetism and mathematical methods of explanation led to a downgrading of the role of mechanics and its displacement as the queen of physics. At the same time mechanical or visually perceptible explanations of microphysical processes became unfashionable and an era began in which it was no longer considered necessary to look for a physical meaning in mathematical operations related to physical objects. In accordance with these developments the inscrutable concept of the aether, which was based on mechanical precepts, began to fall into disrepute, and its downfall was accelerated by the implications of the Michelson-Morley experiment of 1887. On the other hand, the equally inscrutable concept of the field, coinciding in many respects with the aether but used in a mathematical context, began its ascendance.

One of the rearguard actions to save the undermined status of the aether was an explanation, put forward by Lorentz in 1892, of the non-additivity of the mechanical velocity of the Earth and the electromagnetic velocity of light resulting from the Michelson-Morley experiment. Unknown to Lorentz the same explanation was also proposed by Fitzgerald. It was suggested that one arm of the interferometer used in the Michelson-Morley experiment, namely that pointing in the direction of the Earth's motion, may be subject to contraction as a result of motion and to such extent that the expected addition of velocities is annulled. This hypothesis could not be tested, not only because the assumed contraction was extremely small, but mainly because any test arrangement should be expected to experience the same contraction. However, it is of interest to note that the non-contracted and contracted arm were supposed to differ from one another by a factor equal to the square root of $1-v^2/c^2$. We will meet this factor again and it will be referred to as the Lorentz factor.

An obstacle which held up progress in electricity during Hertz's time was the lack of knowledge of the microprocesses on which such things as electric current, electric charge, etc. were based. In this area changes began to occur rapidly after Thomson clarified the nature of negative electric charges in 1897 and postulated the existence of subatomic material particles associated with an elementary quantity of negative electricity, named electrons. This discovery and the advances made in electromagnetic research after Hertz established within a short time the foundations of atomic and particle physics. One of the physicists who participated actively in the development of the theory of electrons was Lorentz. He proceeded from Maxwell's equations and studied the implications arising from electrons in motion.

In a series of papers published between 1899 and 1904 Lorentz devoted some attention to the relationship between electromagnetic phenomena in a moving system and those in a system remaining at rest in order to find an explanation for the negative result of the Michelson-Morley experiment. He argued that the velocity of light, i.e. the velocity of electromagnetic wave propagation as deduced from Maxwell's theory, would be non-additive as required by the Michelson-Morley experiment in a moving system if the same form of Maxwell's equations is preserved in both systems. To preserve the form of the equations or, as it is said, to make them invariant it is necessary to use a mathematical formula which enables electromagnetic as well as spatio-temporal values in the moving system to be expressed in terms of the system at rest, independently from any other reference frame. The formula incorporates the velocity of light and the velocity of the moving system which must be less than the velocity of light. The mathematical device suggested by Lorentz later became known as the *Lorentz transformations*. This name was used first by Poincaré in 1905 shortly before Einstein published his paper. The essential component of the Lorentz transformations is the square root of $1-v^2/c^2$, the Lorentz factor which has already made its appearance in the Lorentz-Fitzgerald contraction, mentioned above, and which had been first applied by Voigt in 1887 in a discussion of wave motion.

A year after Lorentz published his 1904 paper titled *Electromagnetic Phenomena in a System Moving with any Velocity less than that of Light* dealing with the Lorentz transformations, Einstein produced his paper *On the Electrodynamics of Moving Bodies* in which transformations similar to those of Lorentz play a prominent role. It is said, however, in a footnote supplied by Sommerfield in a collection of original papers on relativity, that the 1904 paper of Lorentz was not known to Einstein when he wrote his 1905 paper.

In the introductory paragraph of his 1905 paper Einstein draws attention to the *reciprocal electrodynamic action of a magnet and a conductor* and states that *the observable phenomenon here depends only on the relative motion of the conductor and the magnet, whereas the customary view draws a sharp distinction between the two cases in which either the one or the other of these bodies is in motion.* Einstein's argument is that if we assume *equality of relative motion in the two cases* we find that the electric currents in both cases are *of the same path and intensity.*

In the second paragraph Einstein makes the following far-reaching assertions: (a) that examples like the interaction of magnets and conductors *suggest* that the phenomena of electrodynamics *possess no properties corresponding to the idea of absolute rest*; (b) that the *unsuccessful attempts to discover any motion of the Earth* relatively to the aether *suggest* the same in respect of the phenomena of mechanics; and (c) that the *laws of electrodynamics and optics* are *valid for all frames of reference for which the equations of mechanics hold good.*

Einstein's first assertion, about electrodynamics and the non-existence of absolute rest, is expressed in a curiously insecure and circumlocutory way. But this is probably the best he can do because the far-reaching conclusions which Einstein is attempting to extract from the one example quoted by him are hardly justified by the facts. Einstein is reading much more into the reciprocal relationship between magnets and conductors than the actual situation warrants. He says that electromagnetic effects *suggest* the possibility that there is no absolute rest. A suggestion is not a positive statement, it is a sign of insufficient evidence, doubt and lack of conviction. Furthermore, it is not absolute rest as such which is assumed to be non-existent, but *properties corresponding to the idea of absolute rest.* This can hardly be called straightforward and physically clear language. It appears that we are not really dealing with absolute rest, but with the *idea* of it, and not with real properties, but with *properties corresponding to an idea.* Einstein's expressions belong more to the realm of metaphysics than to that of physics. However, as the subsequent use of his assertion indicates, its status is not that of a metaphysical speculation or an expression of opinion, but of an important piece of concrete empirical evidence providing the main support for one of the two axioms on which the whole theory rests, the relativity postulate.

Specifically, Einstein's first assertion must be rejected and qualified as a non sequitur, because both magnet and conductor do not operate in a vacuum or in separation from a concrete physical environment. This environment includes as a vital and necessary component the experimenter and a man-made laboratory situation based on the terrestrial reference frame. Electromagnetic phenomena are not directly observable or measurable in nature, apart from the physiological and psychological effects of visible light, they require an Oersted or Faraday to design a certain arrangement, to make readings of instruments and to interpret these readings. Secondly, and more importantly, the environment represents an entity of a higher order which, for all practical purposes, is providing an absolute rest frame for the magnet-conductor interaction. This rest frame is not affected at all by any conclusions one is able to draw from the relative motion between magnet and conductor. There is no way, for instance, one could proffer any judgments about the lack of absolute rest in a tennis court by considering only the relative motion of the tennis ball between the players. In the light of such considerations Einstein's argument appears to be plainly ill-conceived.

The situation between magnet and conductor may give rise to the suggestion that all ingredients of electricity and magnetism are predominantly dynamic and restless, but such suggestion cannot be automatically extended to the concept of absolute restlessness because absolutes require different criteria of evidence and reasoning. The concept of absolute rest or absolute restlessness is not primarily an empirical fact, but a product of reasoning. If electromagnetic phenomena provide any premises for arguments in favour of absolutes, they certainly do not support Einstein's assertion, but its contrary. The evidence is there for the assumption of an absolute velocity, that is, absolute motion, of electromagnetic waves. And if a specific velocity or motion can be considered absolute, then the velocity zero in terms of the absolute velocity must be, at least theoretically, equivalent to the state of absolute rest. The practical side of the problem lies in the relationship of the velocities at the interface between the macroscopically mechanical body which is also an atomic emitter and the electromagnetic wave which proceeds from it or is absorbed by it. This is the cardinal problem raised by the Michelson-Morley experiment which is not connected with the interaction of magnets and conductors or with the interaction of two electrons. Einstein's electrodynamics is only a superfluous and unnecessary embellishment.

Einstein's second assertion deals with the *unsuccessful attempts to discover any motion of the Earth* relatively to the aether. For some reason Einstein does not mention the Michelson-Morley experiment by name although the experiment had a great impact on physicists dealing with fundamental problems and on Einstein himself. In fact, Einstein's 1905 paper is nothing more than a response to the Michelson-Morley experiment and an attempt to propose a theory explaining its result. Basically, the experiment indicated that the velocity of light, i.e. the velocity of electromagnetic waves or particles, and the velocity of the Earth in its orbital motion, a mechanical velocity, are non-additive. For reasons which have never been adequately explained by those who proposed solutions, it was assumed that the velocity of light must have the properties of a mechanical velocity. And when the experiment indicated that the assumption may be false, physicists began to propose far-fetched explanations and theories, like contraction of matter and retardation of time, instead of dropping the assumption that the velocity of light is a mechanical velocity. Unfortunately, the leading theoretical physicists of the day, including Lorentz and Poincaré, preferred to deal with mathematical explanations and disregarded the physical facts of the situation. Einstein followed in their footsteps. The implications arising from this development will be examined in more detail in a separate chapter. Suffice it to say that the result of the Michelson-Morley experiment and similar, but less significant, tests does not contain any evidence for the non-existence of absolute rest.

Einstein's third assertion, that the *laws of electrodynamics and optics* are *valid for all frames of reference for which the equations of mechanics hold good*, is clothed in indirect language similar to the one used for the first assertion. We notice that optics appears from nowhere. Why optics? Maxwell predicted that light is an electromagnetic phenomenon and his prediction was confirmed. But the laws of optics deal with the geometrical properties of light rays and have primarily no common ground with electromagnetism. It is true that another branch of optics developed which deals with the interaction of light with the atomic structure of matter, but this branch was not as yet established when Einstein was writing his paper and the interaction it deals with is not the subject of Maxwell's equations or what Lorentz and Einstein call *electrodynamics*. There is no point in hinting at some fundamental insight being gained by connecting optics with mechanics via electrodynamics when nothing further is offered to elucidate the hint. It appears that the only function of the reference to optics is to create the impression that what Einstein has to say subsequently is applicable to a wide range of physical phenomena.

Most probably the meaning of Einstein's third assertion is that situations in which Maxwell's equations apply are also subject to mechanical laws. Two interacting electrons, or conductors and magnets, are carriers of electricity and magnetism, but they are also material bodies with mechanical properties. This statement adds nothing new or significant to our knowledge. Why is it necessary to draw attention to a known and accepted fact? The answer must be looked for in Einstein's desire to provide a link leading to his two axioms or postulates which he announces immediately after his third assertion. Emphasising the connection or equivalence between electrodynamics and mechanics lends support to the view that all velocities are, or ought to be, physically equivalent and mathematically additive, and this includes the velocity of light. It also gives the opportunity to present light as a kind of quasi-mechanical link in the chain of Einsteinian two-system interaction. The electromagnetic transfer of energy is the link between electrically or magnetically active bodies and these bodies are also mechanically active. There is some reason to assume, according to Einstein, that the electromagnetic transfer of energy has some function in the mechanical interaction of two bodies. This assumption prepares the way for the formulation of Einsteinian kinematics as deduced from the postulate of the constancy of light velocity. This postulate is the second basic axiom on which the special theory is allegedly built. The short and unconvincing mixture of laws and equations with reference frames and three branches of physics is considered sufficient to establish the validity of two fundamental premises for the whole of physics.

Einstein disregards the essential dissimilarities between electrodynamics and mechanics. He does not acknowledge the fact that electromagnetic waves and mechanical matter are two disparate states of existence and that there is no physical reason why the velocity of light should be a priori additive with other velocities. The uniqueness and absoluteness of the electromagnetic wave propagation cannot be deduced from, or reconciled with, any mechanical principles. It could even be said that it is contrary to Newtonian mechanics which does not limit speeds in any way. And in 1905, when Einstein first formulated his axioms, he explicitly accepted Newtonian mechanics. His kinematical theory, for instance, begins with the words: *Let us take a system of co-ordinates in which the equations of Newtonian mechanics hold good.* Mechanics deals with macroscopic bodies in motion and their interaction by direct contact. It has nothing to say about how forces act at a distance, although it has been assumed that they act instantaneously. But since Einstein's mechanics is restricted to kinematics the action of forces is not involved. The electromagnetic state of matter, on the other hand, has no influence on the mechanical motion of bodies, except in a very minute way which was not taken into account in 1905 and continues to be disregarded in mechanics. Its interaction with the atomic state is limited to emission, absorption, reflection and similar processes which do not affect mechanics. And the concept of the luminiferous aether, which was supposed to have quasi-mechanical properties and therefore to constitute a link between mechanics and light, is specifically rejected by Einstein.

Einstein also disregards the theory of electrons which had sufficiently advanced by 1905 to expose the nature of the microphysical processes on which electricity and magnetism are based. Einstein's conductor is a complex dynamical system of moving electrons. The situation is even more complex because electrons can move without a conductor. Furthermore, electrons are also magnets. All these phenomena are difficult to reconcile with Einsteinian distinct co-ordinate systems in relative motion. How are co-ordinates of moving electrons or of one moving electron determined? What exactly is the meaning of "system" in microphysics? Is one electron a "system"? Or an electric current in a wire, or a bundle of free electron rays? Which entities are in a relativistically significant "relative" motion? What are the practical means of making observations in microphysics which would enable us to speak meaningfully about Einsteinian relative motion between two independent systems? The fact is that two electrons never exist in isolation and that any observation would materially affect their motion. The problems arising from the theory of electrons reveal not only the intrinsic difficulties in microphysics and the differences between electrodynamics and mechanics, but also the crudeness of the Einsteinian scheme and its utter unsuitability in the realm of microphysics.

Generally speaking, the injection of electrodynamical considerations into the special theory and the use of the term "electrodynamics" by Einstein must be criticised because (a) in many statements the scope and meaning of electrodynamics is restricted to electromagnetic phenomena, and frequently only to the velocity of propagation, and is not necessarily related to the behaviour of conductors and magnets which are initially quoted as supporting evidence; (b) mechanically the behaviour of conductors and magnets is not different from the behaviour of other mechanical bodies under the influence of forces and does not have to be separated from dynamics in general; and (c) the presence of strong forces in all electrodynamical considerations is quite contrary to the letter and spirit of the kinematical theory which is the principal idea of the 1905 paper and which is specifically restricted to systems of co-ordinates in uniform and rectilinear motion. Why under these circumstances Einstein bothers to talk about conductors and magnets and includes an *electrodynamical part* in his 1905 paper, pretending that this is where his kinematics finds its practical application, is a complete mystery.

In the *electrodynamical part* Einstein indicates how his relativity postulate and the Lorentz factor can be applied to restate mathematically Maxwell's equations, the Doppler effect, aberration, radiation pressure and the slowly accelerated electron. It is needless to repeat that all these applications are of no significance to physics and also completely outside the scope of special relativity. They are artificial and unnecessary complexities proving that mathematics can be divorced from physical reality. What possible use are Maxwell's equations in a relativistic "Lorentz-invariant" form? Apart from giving some questionable satisfaction to theoretical physicists and mathematicians, the relativistic form of the equations does not serve any purpose. There is no doubt that mathematically a situation can be expressed in different ways and all of them will be formally correct. In the case of the tennis players, for instance, we could eliminate the tennis court and immobilise mathematically one or the other of the two players. All motions of the moving player and the tennis ball can then be described in terms of the player considered at rest. But we don't do this because it de-visualises an intuitively clear and simple sequence of events and introduces considerable unnecessary and unnatural complexities, and what is even more important, because it disregards the absolutely essential framework and environment in which things occur and ultimately completely falsifies the real physical situation.

The development of electromagnetism at the beginning of the 20th century posed several problems for physicists which, although predominantly of theoretical nature and not of immediate practical significance, nevertheless had the potential of greatly influencing the future progress of physics. Among these problems were the non-instantaneity of electromagnetic action at a distance, the limiting nature of the velocity of light and the non-additivity of the velocity of light. Einstein neglected to give these problems the careful, balanced and close attention they required and proposed hasty solutions which lacked insight and objectivity and complied primarily with mathematical requirements and not with physical conditions. In relation to non-instantaneity the medium and its potential interaction with, or influence on, electromagnetic radiation was written off and its examination as a physically significant factor was completely discouraged. In its place the entirely mathematical concept of the field was introduced. A taboo was placed on raising the question as to what the field could mean in physical terms. The limiting nature of the velocity of light was derived from a mathematical formula, the Lorentz transformation, without any attempt to search for the physical basis and to study the non-mathematical implications. The non-additivity of the velocity of light was interpreted in a peculiar manner which opened the way for the mathematical elimination of absolute space and time and cast doubt on the foundations of physics without any necessity. It is to be hoped that the time will come soon when the imposition of Einsteinian patterns of reasoning and interpretation can be completely terminated and the Einsteinian influence removed from physics. In particular, the medium, the total environment and the hierarchical structure of reality should be freed from mathematical restrictions, and Maxwell's equations and the electromagnetic field should not be used as shackles inhibiting the progress of physics.