MedCrave
Step into the World of Research

Physics & Astronomy International Journal

Mini Review

Open Access

Electrokinetic field and its waves

Abstract

In this work, we have elucidated the role of the so–called electrokinetic field in the well–known phenomenon of electromagnetic induction and have investigated the theoretical possibility of the existence of electrokinetic waves.

Keywords: electromagnetic induction, magnetic field, density, mutual creation, maxwell's equations, magnetic vector

PACS: 04.50.Kd; 04.30.–w

Volume 2 Issue 4 - 2018

Andrew Chubykalo
Academic Unit of Physics and Chemical Sciences, Autonomous University of Zacatecas, Mexico

Correspondence: Andrew Chubykalo, Academic Unit of Physics and Chemical Sciences, Autonomous University of Zacatecas, Apartado Postal C–580 Zacatecas 98068, ZAC, Mexico, Email achubykalo@yahoo.com.mx

Received: July 24, 2018 | **Published:** August 20, 2018

Introduction

Electromagnetic induction is frequently explained as a phenomenon in which a changing magnetic field produces an electric field and a changing electric field produces a magnetic field. However, in Maxwell's equations, electric and magnetic fields are linked together in an intricate manner, and neither field is explicitly represented in terms of its sources. So an examination of the causal relations in time–dependent electric and magnetic fields presented by Jefimenko[1] shows that Maxwell's equations *are not at all causal equations*, and that *neither of two fields can create the other*. The conclusion of Jefimenko[1] that electric and magnetic fields do not create each other is not entirely new, see e.g., the paper "Does the displacement current in empty space produce a magnetic field?"[2]

As it was shown in,[1] the *causal* equations for electric and magnetic fields in a vacuum are

$$\mathbf{E}=\frac{1}{4\pi\varepsilon_0}\int\left\{\frac{[\varrho]}{r^2}+\frac{1}{rc}\frac{\partial[\varrho]}{\partial t}\right\}\mathbf{r}_u dV'-\frac{1}{4\pi\varepsilon_0 c^2}\int\frac{1}{r}\left[\frac{\partial\mathbf{J}}{\partial t}\right]dV' \tag{1}$$

and

$$\mathbf{H}=\frac{1}{4\pi}\int\left\{\frac{[\mathbf{J}]}{r^2}+\frac{1}{rc}\frac{\partial[\mathbf{J}]}{\partial t}\right\}\times\mathbf{r}_u dV', \tag{2}$$

where the square brackets in these equations are the retardation symbol indicating that the quantities between the brackets are to be evaluated for the time $t'=t-r/c$, where t is the time for which $\mathbf{E}$ and $\mathbf{H}$ are evaluated, ϱ is the electric charge density, c is the velocity of light, r is the distance between the field point x,y,z (point for which $\mathbf{E}$ and $\mathbf{H}$ are evaluated) and the source point x',y',z' (volume element dV'), and $\mathbf{r}_u$ is the unit vector directed from dV' to the field point, $\mathbf{J}$ is the current density. The integrals in both equations are extended over all space.

One can see from these equations that the electric field has *three* causative sources: the charge density ϱ, the time derivative of ϱ, and the time derivative of $\mathbf{J}$. In addition, one can see that the magnetic field has *two* causative sources: the electric current density and the time derivative of $\mathbf{J}$.

According to these equations, in time–variable systems electric and magnetic fields are always created simultaneously, because they have a common causative source: the changing electric current [the last term of Equation (1) and the last term in the integral of Equation (2)]. Once created the two fields coexist from then on without any effect upon each other. Therefore electromagnetic induction as a phenomenon in which one of the field creates the other *is an illusion*. The illusion of the "mutual creation" arises from the facts that in time–dependent systems the two fields always appear prominently together, while their causative sources (the time–variable current in particular) remain in the background.

However, if the two fields are created simultaneously and coexist from then on as a dual entity, then the common concept of electromagnetic induction requires a through reexamination. Jefimenko[1] have made such reexamination.

Electrokinetic field

What is then the true nature and cause of "electromagnetic induction"? The answer to this question can be found in Jefimenko[1] and this answer is quite simple. According to Equation (1), a time–variable electric current creates an electric field parallel to that current [the last term of Equation (1)]. This field exerts an electric force on the charges in nearby conductors thereby creating induced electric currents in them. Thus, the term "electromagnetic induction" is actually a misnomer, since no magnetic effect is involved in the phenomenon, and since the induced current is caused solely by the time–variable electric current and by the electric field produced by that current.

Observe that the electric field produced by a time–variable current differs in two important respects from the ordinary electric field produced by electric charges at rest: the field is directed along the current rather than along a radius vector, and it exists only as long as the current is changing in time. Therefore, the electric force caused by this field is also different from the ordinary electric (electrostatic) force: is directed along the current and it lasts only as long as the current is changing. Unlike the electrostatic force, which is always an attraction or repulsion between electric charges, the electric force due to time–variable current is a *dragging* force: it causes electric charges to move parallel (or antiparallel) relative to the direction of the current. If the time–variable current is a convection current, then the force that this current exerts on neighboring charges causes them to move parallel to the convection current, rather toward or away from the charges forming the convection current [the total electric force is, of course, given by all three terms of Equation (1)].

The electric field created by time–variable currents is very different from all other fields encountered in electromagnetic phenomena. So Jefimenko[1], taking into account that the cause of this field is a motion of electric charges (current), gives to it the special name the *electrokinetic field*, and to the force, which this field exerts on an electric, charge the *electrokinetic force*. Of course, one could simply call this field the "induced field". However, such a designation would not reflect the special nature and properties of this field. Note, however, that the term "electrokinetic" is also used in reference to phenomena associated with the movement of charged particles through a continuous medium or with the movement of a continuous medium over a charged surface. These phenomena have no connection with the electrokinetic field defined in Jefimenko[1]. Another appropriate name for this field is the "Faraday field" introduced by Beckmann[3]. We shall designate the electrokinetic field by the vector $\mathbf{E}_k$. From Equation (1) we thus have

$$\mathbf{E}_k = -\frac{1}{4\pi\varepsilon_0 c^2}\int \frac{1}{r}\left[\frac{\partial \mathbf{J}}{\partial t}\right] dV'. \tag{3}$$

Although we have been discussing the electrokinetic field as the cause of induced currents in conductors, its significance is much more general. This field can exist anywhere in space and can manifest itself as a pure force field by its action on free electric charges. Of course, because of c^2 in the denominator in Equation (3), the electrokinetic field cannot be particularly strong except when the current changes very fast. This is probably main reason why this field was ignored in the past. Another reason is the temporal (transient) nature of this field.

But even a weak electric field can produce strong currents in conductors, and that is why the current–producing effect of the electrokinetic field is much more prominent than its force effect on electric charges in free space.

If we compare Equation (3) with the expression for the retarded magnetic vector potential $\mathbf{A}^*$ produced by a current $\mathbf{J}$.[4]

$$\mathbf{A}^* = \frac{\mu_0}{4\pi}\int \frac{[\mathbf{J}]}{r} dV', \tag{4}$$

We recognize that the electrokinetic field is equal to the negative time derivative of $\mathbf{A}^*$ (observe that $\mu_0 = 1/\varepsilon_0 c^2$:

$$\mathbf{E}_k = -\frac{\partial \mathbf{A}^*}{\partial t}. \tag{5}$$

It is interesting to note that Equation (5) points out to a possibility of a new definition and interpretation of the magnetic vector potential. Let us integrate equation (5). We obtain

$$\mathbf{A}^* = -\int \mathbf{E}_k dt + \text{const}. \tag{6}$$

Let us call the time integral of $\mathbf{E}_k$ the *electrokinetic impulse*. We can say then that the magnetic vector potential created by a current at a point in space is equal to the negative of the electrokinetic impulse produced by this current at that point when the current is changed. Since the electrokinetic impulse is, in principle, a measurable quantity, we thus have an operational definition and a physical interpretation of the magnetic vector potential. Note that E. J. Konopinski gives a related interpretation of the magnetic vector potential.[5]

It is useful to mention that although Equations (5) and (6) correlate the electrokinetic field with the magnetic vector potential, there is no causal link between the two: the correlation merely reflects the fact that both the electrokinetic field and the magnetic vector potential are simultaneously caused by the same electric current. It is important to note that the electrokinetic field has not been studied (or even recognized as a special force field) until now, although the fact that the time derivative of the retarded vector potential is associated with an electric field has been known for a long time.

As it is known,[6] the divergence of the retarded magnetic vector potential $\mathbf{A}^*$ satisfies the Lorentz's condition

$$\nabla \cdot \mathbf{A}^* = -\frac{1}{c^2}\frac{\partial \varphi^*}{\partial t}, \tag{7}$$

where φ^* is the retarded scalar potential of $\mathbf{E}$. Therefore, by Equations (5) and (7), we have

$$\nabla \cdot \mathbf{E}_k = \frac{1}{c^2}\frac{\partial^2 \varphi^*}{\partial t^2}. \tag{8}$$

For the curl of $\mathbf{E}_k$ we have, by Equation (5) and by the definition of the magnetic vector potential,

$$\nabla \times \mathbf{E}_k = -\frac{\partial \mathbf{B}}{\partial t}. \tag{9}$$

Now, taking into account Equation (9) and that

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t},\ \mathbf{D} = \varepsilon_0 \mathbf{E},\ \mathbf{B} = \mu_0 \mathbf{H}, \tag{10}$$

we have, noting that $\mu_0\varepsilon_0 = 1/c^2$,

$$\nabla \times (\nabla \times \mathbf{E}_k) = -\mu_0 \frac{\partial \mathbf{J}}{\partial t} - \frac{1}{c^2}\frac{\partial^2 \mathbf{E}}{\partial t^2}, \tag{11}$$

where $\mathbf{E}$ is the total electric field given by Equation (1). According to vector analysis, we have

$$\nabla \times (\nabla \times \mathbf{E}_k) = \nabla(\nabla \cdot \mathbf{E}_k) - \nabla^2 \mathbf{E}_k. \tag{12}$$

For $\nabla(\nabla \cdot \mathbf{E}_k)$ we have, by Equation (8), by the definition of the retarded scalar potential,[4] and by Equation (5),

$$\nabla(\nabla \cdot \mathbf{E}_k) = -\frac{1}{c^2}\left(\mathbf{E} + \frac{\partial \mathbf{A}^*}{\partial t}\right) = -\frac{1}{c^2}\frac{\partial^2}{\partial t^2}(\mathbf{E} - \mathbf{E}_k). \tag{13}$$

Substituting Equation (13) into Equation (12) and comparing the result with Equation (11) we finally obtain

$$\nabla^2 \mathbf{E}_k - \frac{1}{c^2}\frac{\partial^2 \mathbf{E}_k}{\partial t^2} = \mu_0 \frac{\partial \mathbf{J}}{\partial t}, \tag{14}$$

which is an equation for a $\mathbf{E}_k$ –wave propagating in space with the velocity c .

Conclusion

In his book,[1] Jefimenko asks the question: are there some effects of electrokinetic fields and forces that have not yet come to light? There probably are. They would be most prominently associated with very strong and rapidly changing electric currents. Electric spark discharges are good examples of such currents. Spark discharges should have significant effects on nearby charged particles, causing them to move along the spark. As a consequence, the spark itself could spread laterally and could give rise to secondary discharges. It is theoretically obvious that the electrokinetic field of rapidly varying currents reaches the object to which it acts as waves Equation (14) of this field. It would be interesting to see to what extent such effects do actually accompany bolts of lightning.

Following[1] we have elucidated that the essence of the induction phenomenon is that the electrokinetic fields, just like electrostatic fields, are force fields, which are propagated in the form of waves. But the most important thing is that we predict the existence of electric (not electro*magnetic*!) radiation, about technical use of which we can only guess for now.

Acknowledgements

None.

Conflicts of interest

Author declares there is no conflict of interest.

References

1. Jefimenko OD. *Causality, electromagnetic induction and gravitation: A different approach to the theory of electromagnetic and gravitational fields*. 2nd ed. USA: Princeton University Press; 2000.
2. Rosser WG. Does the displacement current in empty space produce a magnetic field? *American Journal of Physics*. 1976;44(12):1221–1223.
3. Beckmann P. *Einstein plus two*. USA: Golem Press; 1987. p. 108–113.
4. Jefimenko OD. *Electricity and Magnetism*. 2nd ed. USA: Electret Scientific; 1989.
5. Konopinski EJ. *Electromagnetic Fields and Relativistic Particles*. USA: McGraw–Hill; 1981. p. 158–160.
6. Jefimenko OD. *Electromagnetic Retardation and Theory of Relativity*. 2nd ed. USA: Electret Scientific; 2004.