About the materiality of the electromagnetic vector potential

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ABSTRACT. It is shown that the discussion about the materiality of electromagnetic vector potential (for example: [1-5]) reduces to the following dilemma: does it exist short-range interaction or remote action ? In this case we consider the problem in the frame of classical electrodynamics.

1 Introduction

Usually one asserts that the emf (electromotive force) of induction, U, in a closed contour is completely determined by the speed of change of the magnetic flux Φ, penetrating this contour:

$$U = -\frac{\partial \Phi}{\partial t} \tag{1}$$

It is correct for a contour of any form but such a generalized approach veils the physical essence of the process. Here is silently implied, that when Φ does change in time, the lines of magnetic flux, in any way, cross the conductor (where happens the dislocation of the conductivity electrons).

However it is far to be the general case.

In this problem it is interesting to consider a situation when the process of electromagnetic induction occurs in a contour surrounding an indefinitely long solenoid.

As it is known, the magnetic field of such a solenoid is completely concentrated inside; outside the solenoid $H = 0$. But experiment proves, that if an electric current in the solenoid changes in time (for example, for an alternating current), in a contour surrounding this solenoid, also arises an electromotive force of induction, although contour and magnetic field are spatially divided. Moreover, irrespective of the radius of the contour, this induction will have the same magnitude (other conditions being equal), i.e., the emf is independent of the distance between the magnetic flux and the point of dislocation of electrons. This situation looks like a long-range interaction. It is easy to be convinced by this fact, owing to the experiment represented on Fig.1.

2 Experiment.

Let us consider this experiment in more details.

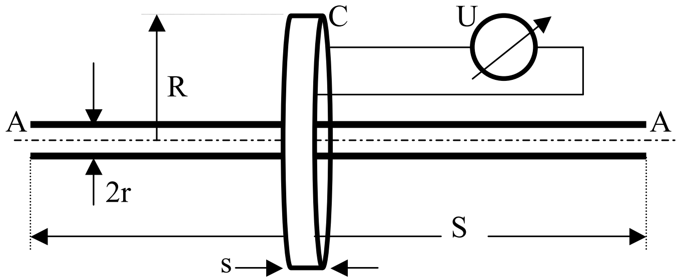

Fig.1. Diagram of the experiment: A-A is a long solenoid, C is the single-layer coil, U is a voltmeter, S/s=100.

Due to a magnetic flux, there arises a circulation of the vector potential, $\vec{A}$, and we have :

$$\Phi = \oint \vec{A} d\vec{l} \tag{2}$$

In the axial-symmetric case

$$A = \frac{\Phi}{2\pi R} \tag{3}$$

The field of the vector potential exists outside of the solenoid everywhere from $R = r$ (radius of the solenoid) up to $R = \infty$ (we consider only the external surface of the solenoid).

When an alternating electric current flows through the solenoid , we have both $\partial\Phi/\partial$t and $\partial A/\partial t$ different from zero, and thus arises the electric field $\vec{E}$:

$$\vec{E} = -\frac{\partial \vec{A}}{\partial t} = -\frac{\pi r^2 \frac{\partial \vec{B}}{\partial t}}{2\pi R} \tag{4}$$

Here we suppose that the potential gradient equals zero : $\nabla\Phi = 0$. $\vec{B}$ is the magnetic induction in the solenoid.

The electric field as well as the field of the vector potential exist in the limits $r \leq R \leq \infty$, so that the conductivity electrons of the coil C are in this field too. This fact gives a ground to believe, that the emf induction is a consequence of the interaction of the conductivity electrons with this field $\vec{E}$.

In this case we may speak of a short-range interaction.

Let us calculate the emf of the induction, $U_{0,}$ for a single turn :

$$U_0 = \oint \vec{E} d\vec{l} = -\frac{r^2}{2R}\frac{\partial B}{\partial t} 2\pi R = -\pi r^2 \frac{\partial B}{\partial t} = -\frac{\partial \Phi}{\partial t} \tag{5}$$

Or $U = NU_0$, where N is the number of turns (U is independent of R, Fig.2).

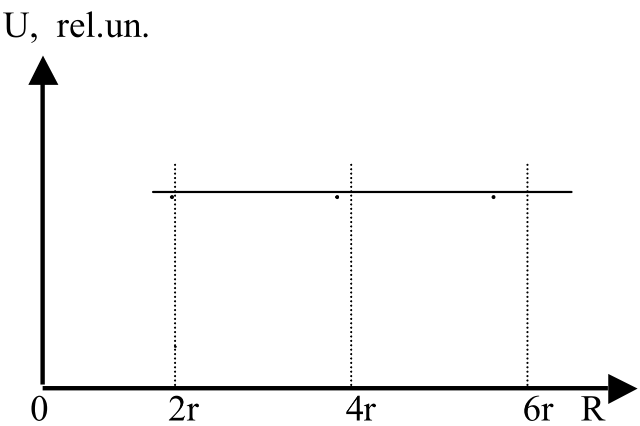

Fig.2. Plot of emf, U, as a function of R. Points are the experimental ones.

3 Conclusion.

Thus, if we explain the given experiment within the frame of the concept of short-range interactions we are obliged to consider both the field $\vec{E}$ and its source, the vector potential field $\vec{A}$ as an objective physical material substance: potential $\vec{A}$ is *attributum* of the electromagnetic field but not only a convenience without physical reality.

References

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