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A DIFFICULTY IN ELECTROMAGNETIC THEORY

by Arnold Lynch and Ivor Catt

We seem to have two different systems of electrical theory almost but not quite independent of each other. The difficulty has existed for more than a hundred years but appeared unimportant until the last twenty years or so. There are, for example, two words "dielectric" and "insulator" to mean the same thing. Faraday discovered that there were materials in which the electric field was stronger than in air, and he wanted a word to describe them. At his request William Whewell, who was regarded as an expert on everything, invented "dielectric" using the Greek "dia", meaning "through" (as in "diameter"). If we go down-market to Latin instead of Greek, we find these materials being called "insulators" from the Latin word for an island, meaning that the electricity is marooned on them and cannot escape. So these materials both do and do not let electricity through them, but of course there are two different electricities here – field and charge. Usually we can choose easily enough which kind of theory to use: charges and currents for most low-frequency problems, and fields for high frequencies. But sometimes we need both theories in the same problem, and they may conflict.

Faraday himself was no mathematician, but his picture of electric fields as lines of force and, more exactly, tubes of force, gave Clerk Maxwell a basis for mathematical expressions which are known to us as Maxwell's Equations (though they are written nowadays in a form Maxwell never saw, in notation invented by Oliver Heaviside). They take into account the electrical permittivity of the ether and its magnetic permeability, and the way those properties change in dielectric and magnetic materials. They do not include anything about mass. Maxwell used these equations to show the possibility of setting up a wave-motion in the ether, with the waves travelling at approximately the same velocity as light. In the late 1880's Hertz demonstrated that these waves could be produced and detected.

We use the word "ether" without apology. The modern term "free space" means nearly the same thing, but without the mass which caused the ether to be discredited a hundred years ago. It has four known properties: capacitance, inductance, wave velocity, and impedance; from any two of them, the other two can be deduced.

It is unprofitable to try to use models to represent the ether (or perhaps almost anything else). Mechanical models fail if the scale is much smaller or much larger, because in general the properties of materials do not change with scale. Thus an elephant magnified ten times would collapse under its own weight. Purely mathematical models avoid this trouble, but there is another objection which was noticed in another context by Tom Lehrer. Life, he said, is like a sewer: what you get out of it depends on what you put in. This is also true of models. Kelvin's theory of the ether failed because he put in the properties of a solid, including mass and elasticity. Maxwell's theory of the ether was better because he put in less -- but perhaps even Maxwell put in too much.

In 1896, after Röntgen discovered X-rays and their ability to make air conduct electricity, J. J. Thomson (always known as "J. J.") set out to investigate what it was in the air that made it conduct. He discovered the electron, but neither he nor anybody else has ever seen an electron or even photographed one. The important part of his discovery was that the electric charge carried by the electron was always associated with mass. Many people had thought that atoms of electricity would some day be found, but nobody had expected them to have mass, and nobody (not even J. J.) had expected the mass to be only a small fraction of the mass of an ordinary atom. Here is the first sign of serious conflict between the two kinds of theory: J. J. had used Maxwell's Equations to

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calculate how the electrons should behave, but now he had shown that the electrons had mass, which was not included in Maxwell's Equations and so would need them to be modified. This was a logical problem akin to sawing off the branch you are sitting on, but there was a worse problem still – that an electron forming part of an atom would have to be moving rapidly to avoid being caught by a positive charge somewhere in the atom; and if it was moving round some centre it would, according to Maxwell's Equations, radiate an electromagnetic wave. J.J. knew that he needed to explain why the electron was not captured and neutralised and yet did not radiate, but he never found a good enough theory. When Bohr found an explanation ten years later, J.J. did not like it, and never quite gave up his own ideas, which he still included in his lectures to undergraduates as late as 1933 (ref. 2).

Bohr's new theory was that electrons were in orbit around a central positively-charged nucleus, and that they did not radiate as Maxwell's equations predicted. Those equations describe a material which has no molecular or atomic structure, and electric charge that has no mass; so why *should* they apply within an atom? The great point in favour of Bohr's theory was that it predicted very accurately the spectrum of the light emitted by hydrogen atoms, using only one disposable constant – and that constant is equal to the one that Planck had introduced in 1900 to explain the distribution of energy in the spectrum of a hot body, and also equal to the constant that Einstein had introduced in 1905 in his explanation of the photo-electric effect. Evidently it was a general-purpose constant. This model of the atom was further improved by the idea that electrons might spin – always at the same speed, and in a direction often either the same as, or directly opposite to, that of their neighbours.

Another new idea about electrons appeared in the 1920's: it was recognised that waves might behave like particles, which is not implausible, and particles could behave like waves, which was surprising. But it was true, and electron diffraction was seen and photographed. (One of the people who did it was J.J.'s own son, G. P. Thomson.) Electric charge can behave like a group of waves, but these are not electromagnetic waves in the ether; they seem to be waves of probability describing the chance of finding an electron in a particular place. That completes our description of electromagnetic waves and of electric charges.

Now we describe a problem which combines the two types of theory and shows the difficulty mentioned in the title of this paper. It arose about twenty years ago when fast-operating silicon chips were to be connected to one another. We idealise the problem slightly. Imagine a coaxial transmission line terminated by a matched load at the far end; and for simplicity let it be evacuated, and of very low resistance. Apply a step voltage to its input; a wave travels along it with the velocity of waves in free space. So after a short time a current begins to flow in the terminating load; that is, electrons start to move through it. The problem is – where did they come from? Not from the input, because electrons have a finite mass and so they cannot travel at the velocity of waves in free space. (Remember that we are considering a step voltage, not an alternating one.)

One of us sent this problem to various people who might have been expected to provide an answer, and the responses were mainly of two kinds (ref. 1): (1) that the wave causes radial movements of the electrons in the line as it passes over them, and that electrons displaced in this way at the far end make up the current; or (2) that electrons move along the line, with velocity less than that of the wave, but push other electrons on in front of them, keeping pace with the wave.

This problem was mentioned in the Institution's Wheatstone Lecture last December. The lecturer said that electrons in a metal travel only slowly but that they can transmit a fast electromagnetic wave by "nudging" their neighbours ("nudging" was his word for it). Our comments on this are: each atom in a metal contributes a few free electrons, so there are rather more electrons than atoms and therefore they are spaced from each other by a little less than the spacing of the atoms – say about a tenth of a nanometre. The size of an electron is not known, but it is presumably much smaller than an atomic nucleus, which is about a millionth of a nanometre. That is, the electrons are spaced apart by more than 100 000 times their diameter. So they cannot deliver a nudge without moving, and they cannot move instantaneously because of their mass.

Our view is that you can believe in the wave-equations, or you can believe in electric charges, but you should not believe in both. If you have to choose, it might be on the basis that electromagnetic waves are produced by charges; or, the other way round, that charges may be caused by waves; and so we might know which to prefer as the reality. We can try treating a more familiar subject to treat in this way: do voltages cause currents to flow, or do currents create potential differences? Most people assume that voltages cause currents, and this answer is based on experience of low-impedance sources whose voltages do not change much under load. Constant-current sources are less usual, though not unknown --the first public electricity supply in Brighton was a constant-current one. In this case it is natural to say that the current creates potential differences. In telecommunication circuits, often the impedances at the input and output are matched, and then neither answer is quite right; we can only say that power is being transmitted, and that both the current and the potentials are governed by the power and the impedance. Just possibly, the answer about electrons and waves might involve some other quantity too.

We return to the main problem. Either answer -- electrons cause fields, or fields cause electrons to move -- is acceptable logically. If electrons are the fundamental entities, then the electromagnetic field has a status rather like that of an isobar on a weather map; useful, but not "real", because you cannot find one by searching in the real world. If this view of our main problem is right, then Maxwell's Equations are only approximate, as no wave could travel faster than electrons can.

Alternatively, consider the other solution: the field may be the fundamental reality, as Heaviside suggested. All electromagnetic energy resides in travelling fields, and the function of conductors is to guide the waves by excluding them partly or totally from the conducting region. The discontinuities at the surfaces are mathematical concepts which might not correspond to any physical object, but they can be thought of as electrical charges. The charges are superfluous to the essentials of the theory, and if charges are to be associated with mass they are not merely superfluous but they cause paradoxes.

Our message, then, is this: you may accept Maxwell's equations as useful approximations; or you may accept them as exact, but if so you will have to modify the theory of electrons and the mass associated with them. You cannot have them both.

(When this paper was read , there was a discussion in which it was suggested that the most fundamental entity is probably the photon rather than a system of waves. It seems impossible, however, to synthesise a step-wave from photons; the photons consist of alternating waves, but the step-wave has a zero-frequency component. Here is a paradox indeed.)

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http://www.ivorcatt.co.uk/x5cz2.htm

In preparation

Chris,
The enormity of the situation comes over me.

Your IEE/IET totallly blocked cattq
http://www.ivorcatt.co.uk/cattq.htm

A third of a century ago, the IEE Chief Executive chose the IEE top expert, Professor Secker, and he wrote to me his answer. Then seven weeks later he contradicted his answer.

Then he said he was not an expert.

I returned to the Chief Executive, and he refused to replace Secker.

Cattq has been totally blocked from all IEE peer reviewed publications.

The late Dr. Arnold Lynch (who helped in the design of Colossus, which shortened the second world war) did much unpaid work for the IEE for years, setting up a new section of the IEE - "History of .... "

Lynch decided that the IEE had treated Catt unfairly, always blocking his work. Senior executives in the IEE told him they were anxious to publish Catt. Lynch proposed a joint paper on cattq, **http://www.ivorcatt.co.uk/cattq.htm** , and this was agreed. The commitment was made that if rejected, reasons would be given for rejection. Since this problem might be personal, Catt did not write any of the paper, but had his name on it as joint author. Lynch presented it, and it was rejected for publication, no reasons given. Lynch then took it to his friend, the chairman of the IEE section that he himself had set up. It became a paper in the yearly meeting of this section in Norwich. I was careful to keep silent.

There was no response whatsoever for a third of a century, but concerns were raised when on his death, the IEE omitted to publish an obituary, which was however in the IEEE and The Times. **http://www.ivorcatt.co.uk/x5bv.htm** . This is some of the evidence that the technology-free careerists who have hijacked the IEE and IEEE are ruthless.

In preparation. Ivor Catt 4/8/2018