It is extraordinary that such an important statement appeared merely as a letter in a non-peer reviewed journal. It has been ignored for the next 40 years.

WIRELESS WORLD, NOVEMBER 1979

I understand that Aristotelians believed that a force was necessary to keep bodies in motion and that, in the absence of this force, the motion would cease. This theory led them into certain difficulties. For instance a spear, once thrown, appeared to continue to move without a force being present. The philosophers rose to this challenge magnificently with a theory that air, displaced from ahead of the spear, rushed to the rear and generated the requisite force – the theory was saved. Unfortunately they missed the simple point first noted by Newton, that it is in the nature of a moving body to continue to move.

In the same way I fear that Maxwell invented a complex explanation for a very simple phenomenon, ie that electromagnetic radiation, or energy current, moves at the speed of light – and that's all, because that is what energy current does. No mechanism invoking E producing H and H, in return, producing E is required. As for the details of Bell's article – they do not stand up well to close examination.

Then a delay of one year.

I would have thought my intention was quite clear – it was to show, by analogy, how a faulty set of primitives can lead to problems in a theory which necessitate the introduction of ad hoc causality relations. In a similar way I believe that the causality relations alleged to reside in Maxwell's equations (i.e. changing magnetic field producing electric field and changing electric field producing magnetic field) are spurious. A moving body continues to move because that is what moving bodies do; an electromagnetic disturbance or energy current, of whatever distribution, continues to move because this is what energy currents do. In other words the statement "energy current travels at the velocity of light" is a primitive assumption in my theoretical framework which requires no further explanation. In my framework the moving energy current is the simple situation and 'static' electric and magnetic fields are composite.

DISPLACEMENT CURRENT

Professor Bell's article "No radio withou displacement current" in the August issu raises so many issues it is difficult to knov where to start. Rather than deal with th details, I will start with a consideration of th purpose of the article. The title of the articl makes this clear; it is an attempt to defen Maxwell's theory against recent criticism with particular reference to displacemen current.

C.A.M.

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In the first place, it is unwarranted to suggest, as Bell does, that since Maxwell *introduces* the idea of displacement current early in his treatise (the correct title, incidentally, is "A treatise on electricity and magnetism" and Bell appears to be referring to the third edition first published in 1891), this is a proof that he thought of it in connection with simple phenomena. This is just too simplistic; the way Maxwell presents his ideas cannot be taken as a guide to how he thought of them. Much has been written and many papers have been published on the genesis of Maxwell's thought and it is inadmissable for Bell to treat the subject in this superficial way. I would be happy to provide a list of references (about 20) to anyone who would like to study the development of Maxwell's thinking in detail. I suggest Joan Bromberg's paper[1] as a good start to the subject.

There are many errors of detail in the article. Perhaps I could draw attention in particular to the statement that "Maxwell... was at home with vectors." Vector algebra was not invented in Maxwell's time and he never used it. He made some use of Quarterninic formulation of his equations but was not consistent in its use – Maxwell, in fact, never formulated his theory in terms of four equations – this was left to Heaviside who also introduced vector calculus more or less as we know it.

The rest of Professor Bell's article can be found in any elementary textbook on electromagnetic theory; its testament, however, does nothing to establish that theory which is in the process of being replaced by a simpler formulation.

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Reference

1. Bromberg, J. "Maxwell's Electrostatics," *American Journal of Physics* 36, 145-151 (1968).

The author replies:

First, Dr Walton's reference to Aristotelian philosophers is a red herring. I mentioned early speculation about the planets because Newton's theory of gravitation was based on the hypothesis that the same force accounted for objects "falling" to earth (the notorious apple!) and for planets describing *closed orbits* about the sun. It then involves the conceptual difficulty of action at a distance, unless one prefers to postulate fields of force. Incidentally Newton was *not* the first to suggest that a body in motion would so continue if undisturbed. Hobbes in his book "The Leviathan" mentions that it was a subject of discussion whether this be so or not, and himself unhesitatingly chose Newton's answer. Newton's achievement was to formulate the precise law and "prove" it by incorporating it in his complete system of mechanics which was supported by experimental evidence.

In considering the proposed alternative to Maxwell's theory of electromagnetic waves, there are two questions. First, what is an "energy current"? "Current" usually means flow of something; and "energy" seems to me entirely abstract unless qualified by some adjective such as kinetic, electrostatic etc. So what flows? Second, is there a relation, and if so why, between this "energy current" and the observable electric and magnetic effects? For example, the creation of a spark in air by a focused laser beam is consistent with the electromagnetic theory of light.

As regards the chronology of Maxwell's different uses of displacement current, the main point is that he did find use for it other than in the derivation of a wave equation. Others have since found its use in "electrotatics" convenient or even essential. (See footnote to article.) It may be that the logical train of development which I suggested is a *post hoc* rationalisation, but one cannot prove whether or not this was how Maxwell saw it.

The article by Joan Bromberg is entitled "Maxwell's Electrostatics" and details Maxwell's difficulties in arriving at a satisfactory formulation of 'displacement' in electrostatics, based largely on the concept of polarisation. So it is in agreement with the point which I was making: Maxwell regarded 'displacement' as an essential part of the description of electrical phenomena, not just as a device to facilitate the formulation of a wave equation.

Of course most of the content of my article in the August issue is to be found in standard text books. It was written on the supposition that there are many readers of *Wireless World* who have not studied a text book on electromagnetism.

D. A. Bell

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DISPLACEMENT CURRENT

Following Professor Bell's article "No radio without displacement current" (August 1979 issue), I wrote a letter which appeared under the title "Displacement current" (November letters). A reply by Professor Bell to my letter was published in the same issue. I felt that this reply revealed misunderstandings of a fundamental nature regarding the points I was trying to make and I could not see how any useful purpose would be served by my responding to it. Since, however, Professor Bell has restated his arguments in the August 1980 letters it seems that I must reply.

My original letter contains the following two paragraphs:

"I understand that Aristotelians believed that a force was necessary to keep bodies in motion and that, in the absence of this force, the motion would cease. This theory led them into certain difficulties. For instance a spear once thrown, appeared to continue to move without a force being present. The philosophers rose to this challenge magnificently with a theory that air, displaced from ahead of the spear, rushed to the rear and generated the requisite force – the theory was saved. Unfortunately they missed the simple point first noted by Newton, that it is in the nature of a moving body to continue to move.

"In the same way I fear that Maxwell invented a complex explanation for a very simple phenomenon, i.e. that electromagnetic radiation, or energy current, moves at the speed of light – and that's all, because that is what energy current does. No mechanism invoking E producing H and H, in return, producing E is required."

I would have thought my intention was quite clear – it was to show, by analogy, how a faulty set of primitives can lead to problems in a theory which necessitate the introduction of ad hoc causality relations. In a similar way I believe that the causality relations alleged to reside in Maxwell's equations (i.e. changing magnetic field producing electric field and changing electric field producing magnetic field) are spurious. A moving body continues to move because that is what moving bodies do; an electromagnetic disturbance or energy current, of whatever distribution, continues to move because this is what energy currents do. In other words the statement "energy current travels at the velocity of light" is a primitive assumption in my theoretical framework which requires no further explanation. In my framework the moving energy current is the simple situation and 'static' electric and magnetic fields are composite.

Before I leave this point I must make two other observations. Firstly Professor Bell not only seems to misunderstand my argument but to compound this by not even having an adequate grasp of his original article, for he states in both the November 1979 and August 1980 replies that "I mentioned early speculation about the planets because Newton's theory of gravitation ....." My problem is that I can find no such mention of the planets in Professor Bell's article. True, he mentions Jupiter in the context of the propagation of radio waves from the vicinity of this planet, but nothing else.

Secondly, the relevance of Hobbes's *The Leviathan* seems a little dubious. I will admit that my statement that the principle of inertia was first noted by Newton is open to question – I would suggest that it was probably first noted by Galileo and enunciated by Newton – although it seems a little beside the point. Incidentally, I cannot locate the passage in *The Leviathan* which Professor Bell is referring to and wonder whether he in fact means some other work by Hobbes, possibly *De Corpore*. I would in any case be obliged if he could let me have a full reference. Since *The Leviathan* is a work of political philosophy it would be a strange place to make the kind of comments quoted by Bell – but who can tell with philosophers!

Several other points are raised by Professor Bell's letter. Before Maxwell's theory can be "faulted on experimental evidence" we require a definitive statement of that theory. Where is this to be found? Certainly not in Maxwell's *Treatise* since this involves views regarding the aether which would not be acceptable to modern physicists. Perhaps if someone could supply a definitive statement of Maxwell's theory I might be able to suggest some experimental tests.

Professor Bell states that he does not know what the energy current concept is or how it relates to the Poynting vector, yet this is set out in the article by Catt (see "The Heaviside signal," *W.W.* July 1979). It surprises me that, having stated his lack of understanding of the concept, and apparently not having seen the above-mentioned article, he still tries to apply it to loop antennas, etc.

It is extremely unfortunate that the displacement current debate has been cluttered by so many side issues. I feel great sympathy for the impartial reader of this correspondence who is attempting to decide which side of the debate has the greater insight into the subject. I am more or less resigned to the fact that it is impossible to debate the central issues of electromagnetic theory because of the high 'noise level' which is generated by those who defend the established view. Where do we go from here? As Professor Bell says, "Everyone tends to believe what he wants to believe" or, to quote from T. S. Kuhn, ("The structure of scientific revolutions," University of Chicago):

> "Max Planck, surveying his own career in his *Scientific Autobiography*, sadly remarked that 'a new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it'.
>
> "These facts and others like them are too commonly known to need further emphasis. But they do need reevaluation. In the past they have most often been taken to indicate that scientists, being only human, cannot always admit their errors, even when confronted with strict proof. I would argue, rather, that in these matters neither proof nor error is at issue. The transfer of allegiance from paradigm to paradigm is a conversion experience that cannot be forced. Lifelong resistance, particularly from those whose productive careers have committed them to an older tradition of normal

science, is not a violation of scientific standards but an index to the nature of scientific research itself. The source of resistance is the assurance that the older paradigm will ultimately solve all its problems, that nature can be shoved into the box the paradigm provides. Inevitably, at times of revolution, that assurance seems stubborn and pig-headed as indeed it sometimes becomes."

Do we really have to wait for a new generation to grow up before we can countenance changes in the accepted theoretical structure? This is the real problem, not electromagnetism, relativity or mechanics, but how to create a forum in which proper discussion of fundamentals can take place.

D.S. Walton
CAM Consultants

Perhaps Professor Bell (August letters) really should have completed his application of the two "disciplines" of science to both the Maxwell and the Catt, Davidson, Walton theories. CDW's theory certainly has fewer hypotheses than Maxwell's (they only need to define what they mean by energy current). From their theory one can deduce Maxwell's equations (yes, and the famous dD/dt term, which is a mathematical quantity, not a "physical current") as well as Faraday's and Maxwell's laws of electromagnetic induction.

I don't believe Catt, Davidson and Walton have ever attempted to suggest that Maxwell's equations are incorrect, merely that they are at best mathematical devices exceedingly useful for setting university examination questions. They may or may not be correct on this point, but that, of course, isn't what everyone's supposed to be discussing (see the editorial in the May issue).

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