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A Reverse Explanation of Radiation

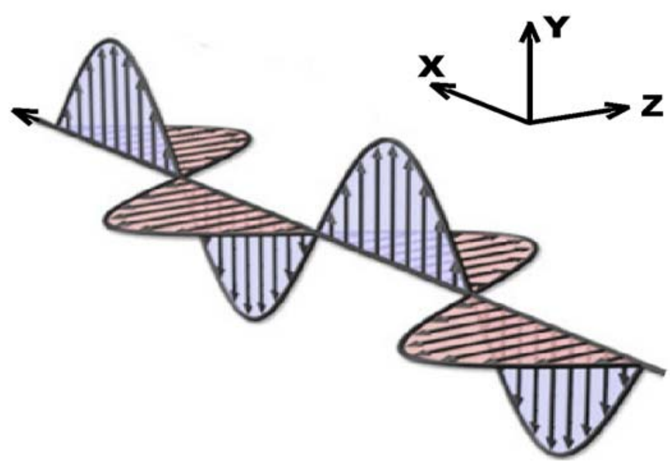
Abstract

There are numerous papers explaining the mathematical relationship between the electric and magnetic fields in electromagnetic radiation. Almost all of them focus on Maxwell's famous equations of electromagnetism. These equations form a concise consolidation of all known experimental results of electricity and magnetism known in Maxwell's day. Although the experimental results of that era were limited, his equations have withstood the test of time, and today's scientists view his equations as gospel for understanding electromagnetism. When his original equations are expressed using modern mathematical syntax they coalesce into four simple vector equations. The fact that only four equations cover almost the entire area of physics involving electromagnetism makes that area of physics seem pretty simple. And since electromagnetism in free space involves only two of the four equations, it makes that subset of physics seem even simpler. However if you're not a physicist, then by the time you work through the intricacies of those two equations it's easy to lose sight of the utter simplicity that they dictate. This paper addresses that problem. It explains radiation in free space differently from other papers. Instead of charging headfirst into manipulating Maxwell's equations to reveal the field relationships of radiation in space, this paper begins with the conclusion that would be reached in doing that, and then addresses the interpretation of the conclusions graphically. It is my hope that this reverse approach will enable more readers to grasp the stark simplicity of Maxwell's dictates, and that it will make the reading of other papers that dig deep into the math more meaningful.

Section 1: Applying Maxwell's Equations To Waves In Space

Consider the drawing shown in Fig.1. It depicts a polarized electromagnetic wave in free space, propagating in the positive X direction.

Figure 1. Polarized EM Wave in Free Space. The electric vector field, **E**, is shown in blue; the magnetic vector field, H, in red. The XYZ coordinate system is oriented so that the E field vectors are all lined up parallel to the Y axis (no X or Z component), and the B field vectors are all lined up parallel to the Z axis (no X or Y component).



The wave depicted is mathematically consistent with Maxwell's four vector equations. However, his first two equations don't apply to phenomena in free space. The two remaining equations which do apply can be simplified by selecting a coordinate system that is aligned to the polarization of the wave. The bottom line is that when Maxwell's equations are customized for a wave like that depicted in Fig.1, the four vector equations morph into the two simple scalar equations shown below.

1. $\partial E_y / \partial x = -\mu_0 \, \partial H_z / \partial t$

2. $\partial H_z / \partial x = -\varepsilon_0 \, \partial E_y / \partial t$

Maxwell's Eq.3 and Eq.4 customized for Fig.1

Eq.1 and Eq.2 stipulate six constraints on the electric and magnetic fields of a wave like that depicted in Fig.1. The constraints are listed below:

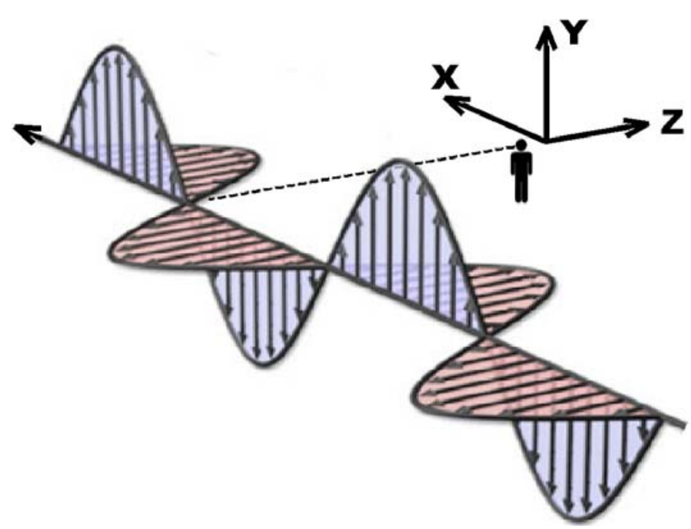
1. The magnitude of the electric field's spatial derivative must relate to the magnitude of the magnetic field's time derivative as specified in Eq.1.
2. The magnitude of the magnetic field's spatial derivative must relate to the magnitude of the electric field's time derivative as specified in Eq.2.
3. The wave's electric and magnetic fields must be orthogonal to the direction of propagation.
4. The wave's electric and magnetic fields must be orthogonal to each other.
5. The wave's electric and magnetic fields must be mirror images of each other.
6. The wave's electric and magnetic fields form a rigid field structure propagating through space.

Constraints 1 and 2 are apparent from the form of the equations. Constraints 3 and 4 are apparent when you scrutinize the subscripts denoting the orientation of the vectors that the scalar magnitudes correspond to. Constraint 5 is apparent when you apply the other four constraints for each moment of time. Constraint 6 is apparent when you show Eq.1 and Eq.2 to be compliant with the wave equation[1,2].

It is important to note that Maxwell's equations **<u>do not</u>** stipulate that the fields must have a sinusoidal shape versus time, as is depicted in Fig.1. The waveform of the fields can be almost any shape as long as they comply with the above constraints. However, Constraint 5 does stipulate that whatever shape one of the fields has, the other field must be a mirror image of that shape. Since the waveform of the fields depicted in Fig.1 is sinusoidal, then the constraints require that the two sinusoidal fields comprising the wave must be spatially orthogonal and spatially and temporally in phase.

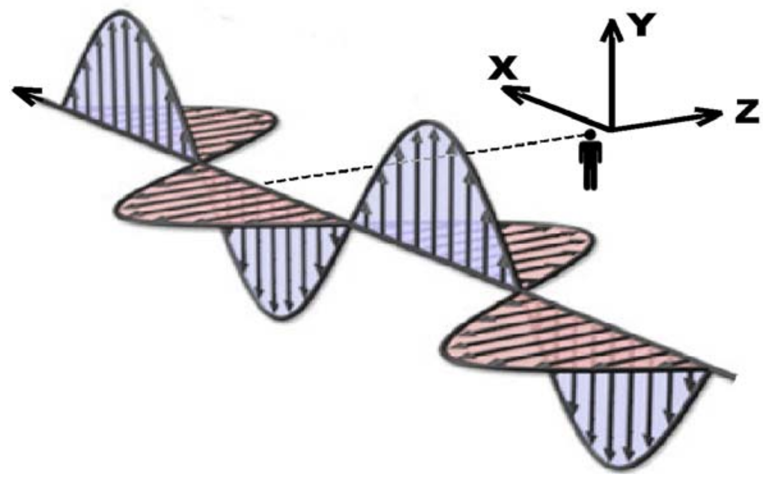
<u>Section 2: Lab Experiments</u>

One way to gain a fair understanding of Maxwell's equations is to conduct some rudimentary lab experiments to verify the compliance of the wave depicted in Fig.1 with Eq.1 and Eq.2. By doing this it will clarify the graphical significance of the equation's mathematical implications. We can do this in an imaginary lab. Referring to Constraint 6 in the previous section, we begin by imagining the drawing in Fig.1 is actually a plastic model. Think of the long black arrow representing the direction of wave propagation as a stiff plastic rod; and the blue and red sinusoids representing electric and magnetic field strength as colored plastic fins glued to the black plastic rod. The plastic model can still be thought of as representing a short burst of energy from some distant transmitting antenna on earth, but imagining the representation to be a plastic model that we can pick up and move around emphasizes the rigid nature of the fields in a propagating wave.

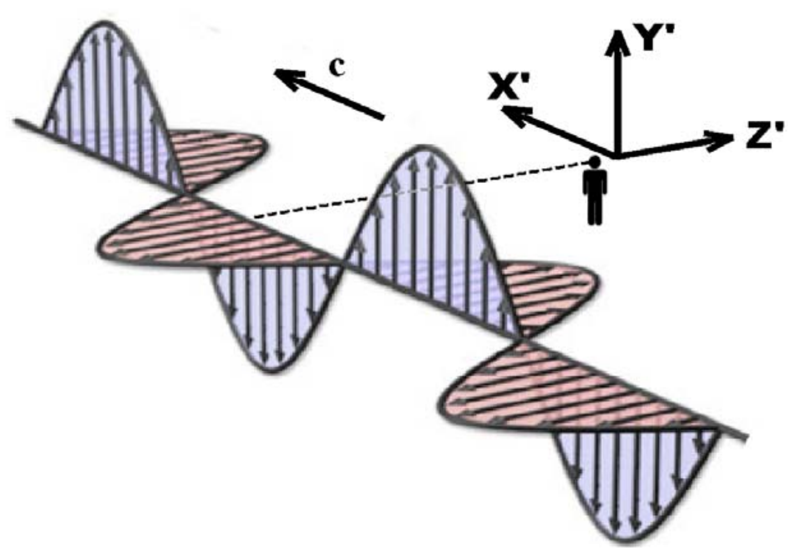


Experiment 1. We begin the first experiment by imagining an observer standing upright parallel to the Y axis and facing in the negative Z direction so he can view the stationary plastic model. The experiment objective is to ascertain the sign of the partial derivative of the fields with respect to X . The experiment setup is shown in the drawing on the right. The observer's line of sight is fixed at a point in the model where the blue electric field and the red magnetic field are both zero. The observer notices that both fields increase in magnitude as he shifts his gaze slightly to his right (the positive X direction). The obvious conclusion is that the partial derivative with respect to X is positive for both fields at the point in space that he is viewing. He decides his next experiment will address the time derivatives at that same point in space.

Experiment 2. Imagine that our observer has very carefully maintained his line of sight fixed on the same point in XYZ space as in Exp.1. While maintaining his fixed line of sight he has his assistant pull the plastic model in the positive X direction to simulate propagation of the wave in the positive X direction. The drawing on the right shows the experiment setup after the plastic model had been pulled a short distance. Actually, all that happened was that the portion of the red and blue fins that were originally on the observer's left, were moved into his fixed line of sight view. The observer noted that as the plastic model moved in the X direction for a few seconds, the field strength depicted at his fixed line of sight point became more negative for both fields. The obvious conclusion is that the partial derivative with respect to time was negative for both fields at the point in space where the partial derivative with respect to X was positive. The observer repeated Exp.1 and Exp.2 for various line of sight starting points, and he soon realized that no matter what starting point he chose, the partial derivative with respect to X of one field is always the opposite sign of the partial derivative with respect to time of the orthogonal field. He notes that the experimental results of opposite sign conform exactly to the sign constraints depicted in Eq.1 and Eq.2.



Experiment 3. Imagine that our observer's line of sight is focused at a point in the plastic model where the two fields are both at their negative max. While maintaining his line of sight fixed on the plastic model, he has his assistant pull both him and the plastic model in the positive X direction at a moderate continuous velocity ***c***. The drawing on the right shows the experiment setup. The observer, who is now in a moving XYZ coordinate system denoted by primes, is not at all surprised that he sees an unchanging plastic model moving along with him. The observer repeats the experiment numerous times, each time having the assistant increase the velocity, ***c***. Each time the observer sees the same thing, a rigid plastic model moving along with him. You might wonder why anyone would conduct an experiment where the outcome was so predictable. The reason is that it emphasizes an important point about radiation that is often misunderstood. If the observer were Superman and the velocity ***c*** the speed of light, and if the fins in the plastic model were actually the electric and magnetic fields that they depicted, then Superman would see a two cycle burst of absolutely rigid electric and magnetic fields moving along with him through space. But, an observer on earth focusing his attention to a point on his X axis would sense the field's magnitude vary with time as the rigid two cycle burst whizzed by at the speed of light … <u>all in exact accordance with Maxwell's equations.</u>



Section 3: Conclusions and Observations

Dynamic Fields vs. Rigid Fields. The experiments emphasize the following important but sometimes misunderstood aspect about radiation in space. An observer in a fixed coordinate system will sense time variations of the fields (dynamic fields) in a burst of radiation as it whizzes by a point in his coordinate system. In fact, the observer will sense that the time variations and the spatial variations are in exact accordance with Maxwell's equations. This fact is demonstrated in Experiments 1 and 2. Conversely, an observer in a moving coordinate system that is travelling with the burst, will sense no time variations of the fields (rigid fields) in his coordinate system; he will sense only an unchanging structure of electric and magnetic fields that remain static forever. The moving observer knows this is not in conflict with Maxwell's equations since those equations only apply to the coordinate system at the birth site of the radiation. This fact is demonstrated in Experiment 3.

Wave Velocity. Maxwell's equations stipulate constraints on the relationship of spatial derivatives and time derivatives that apply to an observer's fixed coordinate system. Notice the parameters μ_0 and ε_0 in Eq.2.. They were included in Maxwell's equations so they would accurately consolidate all experimental results of electricity and magnetism known in his day. They were not included to satisfy experiments in radiation because there were none at that time. However, Maxwell did speculate about radiation. He speculated that if electric and magnetic fields were to propagate as a wave in free space, they would have to satisfy the constraints imposed by his equations. In other words, an observer in a fixed coordinate system would have to perceive the time derivatives of the wave as having a magnitude commensurate with its corresponding spatial derivatives. And, Maxwell knew that the only way that condition could be satisfied would be for the velocity of the wave to be the reciprocal of $(\mu_0 \, \varepsilon_0)^{1/2}$ … which just happened to be the speed of light.

The derivation of the velocity of electromagnetic propagation is actually fairly simply. It begins with the derivation of the wave equation. However, when you endure the agony of working through the derivation of the wave equation in its most general form you will lose any feeling for the graphical significance of what it means. To appreciate the utter simplicity of the wave equation you need to derive it for something simple like the propagation of a polarized wave in an XYZ coordinate system that is aligned to the polarization of the wave. This was done in a one-page paper by Satterfield[1] which emphasizes the rigid nature of propagating fields. With regards to the actual derivation of propagation velocity, it can be done in various ways. Section 5 of Satterfield's *The Birth of a Wave*[2] is an easy to follow derivation.

Radiation Escape Requirements. What conditions spawn radiation? More specifically, what is it that causes the electrical energy trapped in physical devices to suddenly escape the bond of their parental charge, and propagate forever through empty space as autonomous packets of static energy? Maxwell's equations do not answer that question. The equations do define electrical phenomena before and after escape, but not the requirements for bringing about an escape. Obviously an antenna creates the conditions required for radiating the energy supplied to it. An antenna does cause electric and magnetic fields to be temporally and spatially in quadrature, and to occupy the same region of space. Could the requirement for spawning a wave be that simple? Umm … I think there may be more to it than just that. But if you want to read a paper that nibbles at the edge of that question check out Satterfield's *The Birth of a Wave*[2].

Section 4: Referrences

1. The Wave Equation , Satterfield; www.richard-alan.com 12/20/17

2. The Birth of a Wave, Satterfield www.richard-alan.com 12/20/17