The Mediums for Light are Hiding in Plain Sight

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The propagation of light remains one of the enduring mysteries of science. Unlike every other known kind of wave, it travels at a constant speed through empty space without a medium of propagation. What supports its travel in empty space? Why is its speed so constant? And why is it so very fast? Even Einstein gave up trying to puzzle it out and simply stated the propagation of light as a postulate. While Maxwell's equations explain the behavior (the *what*) of light, they don't explain the how or the why. They show that the speed of light is determined by two constants - ϵ_0 and μ_0 - but not why these two constants have the values that they do rather than having some other values. So our questions remain: how does light propagate through empty space and why do ϵ_0 and μ_0 have the values that they do? Maxwell's equations actually do answer these questions. We just haven't understood the message because of our human laundry list of implicit assumptions about the characteristics required of mediums of propagation. As often happens with implicit assumptions, nearly all of them are wrong.

Light has not one but two mediums of propagation. The electric fields in electromagnetic waves are the medium of propagation for the magnetic fields, and the magnetic fields are the medium of propagation for the electric fields. Their dance with each other is what moves light through empty space, much like molecules of air do when propagating sound. Ironically, since the waves of light and the dancing electric and magnetic fields are the same things, the mediums of propagation quite literally have been hiding in plain sight.

This paper examines both the equation for the speed of sound and Maxwell's equations for the propagation of light from a new perspective. In essence, it performs a mathematical autopsy of both to illuminate what lies within and, in the process, solves the mysteries of light's propagation as simply the laws of physics at work.

1. INTRODUCTION

The Michelson-Morley experiment is universally accepted as conclusive proof that light races through empty space at a definite speed c=299,792.5 km/s in the total absence of any medium of propagation whatever.[i] However, all that their experiment actually proves is that there is no stationary medium permeating empty space through which light waves propagate. That by no means rules out a medium of propagation which operates under different laws of physics than those of more familiar kinds of waves.

The design of the Michelson-Morley experiment and the interpretation of its empirical observations were governed by a number of implicit assumptions about the innate nature of mediums of propagation. These implicit assumptions strongly influenced the interpretation of the Michelson-Morley experiment. That influence remains to this day. But as is the case with implicit assumptions, they have not been subjected to rigorous conscious examination. And, in the case of light waves, nearly all of them are wrong. These implicit assumptions include:

- A wave's medium of propagation is physically separate from the wave.[ii]
- The medium of propagation must permeate wherever the wave is able to travel.[iii]
- The medium of propagation is present whether or not the wave is passing through it.[iv]
- The medium of propagation is stationary and the wave travels through it at its speed of propagation.[v]
- The speed at which the wave travels is determined by the physical characteristics of its medium of propagation and the laws of physics which govern them.[vi]

In the case of light waves, only the last assumption is correct. All of the first four are wrong. But our subconscious, unexamined faith in them is what has blinded us from recognizing light's mediums of propagation even though they are clearly described by Maxwell's equations (another example of the human condition at work).

As Maxwell's equations tell us, light has two mediums of propagation, its constituent electric and magnetic fields. A light wave and its mediums of propagation are the same physical entities. The mediums are not stationary. Because the wave and the mediums are the same entities, they move through empty space together. Thus, they only need to be where the wave is; they do not have to permeate the space through which it travels. They are present only when the wave is present. And the wave does not propagate "through" them; they move with the wave. In fact, they are the wave and their dance with each other is both what propagates the wave and determines its speed. Only the last implicit assumption applies to light. Its speed of propagation is determined by the physical behavior of electric and magnetic fields and by the laws of physics which govern that behavior.

2. MAXWELL'S EQUATIONS

Maxwell's equations begin by describing the original source of an electric field; the presence in space of an electric charge.[vii] Maxwell's first equation:

$$\nabla \cdot E = \frac{\rho_{EC}}{\epsilon_0}$$ [viii]

says that the amount of electric field (E) that is coming from a location in space ($\nabla \cdot$) is equal to the density of the electric charge at that location (ρ_{EC}) divided by a constant (ϵ_0). For the moment, we can think of ϵ_0 as a fudge factor to make a proportional relationship between $\nabla \cdot E$ and ρ_{EC} into full equality. This allows us to use the relationship in mathematical calculations with greater precision than when limited to mere proportionality. The name for this kind of fudge factor is "proportionality constant." Like most proportionality constants, its value was determined by experiment. That means someone made careful measurements to figure out what its value had to be to make the two sides of the equation equal.

To better understand Maxwell's first equation, it may be helpful to examine the concepts of electric charge and electric field. Electric charge is an innate characteristic of certain subatomic particles. Protons are tiny particles that usually reside in the nucleus of an atom. Electrons are even tinier particles that orbit the nucleus. The electric charges of the two particles are equal in magnitude but opposite in their behavior. Protons attract electrons and repel protons. Electrons repel electrons and attract protons. Because they were such opposites, protons were declared to have a positive charge and electrons to have a negative charge. (Apparently, protons had better lobbyists than electrons.) However, the + and – designations for the two opposite charges actually turn out to be useful. For example, if we catch 10 electrons and 7 protons and put them into a box, the amount and sign of the box's charge would be:

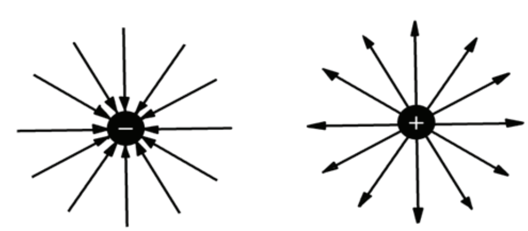
Net charge = - 10 + 7 = - 3

The electrical behavior of the charge in the box would be the same as if we couldn't catch any protons and just threw three electrons into it. Thus, we can think of electric charge both at the particle level and at the level of larger bodies that have either more or fewer electrons than they do protons. In either case, the strength of an electric charge to do things, like push other electric charges around, diminishes as you move away from its source. Thus, electric charge is what's called a point charge. It exists at the location of its origin. The farther you go from that location, the less its presence. However, it still does have a presence, even though diminished.

In the early work on electric charges, their ability to do things at a distance was troubling to those doing the experiments. In mechanical systems, one body can impose a force on another only when in physical contact with it. Electric charges were not limited in that manner. To deal with this effect at a distance, the British scientist Michael Faraday introduced the

FIGURE 1

ELECTRICALLY CHARGED PARTICLES HAVE ELECTRIC FIELDS WHICH EXTEND OUTWARD EQUALLY IN ALL DIRECTIONS



concept of an electric field. As shown in Figure 1, an electric field extends outward in all directions from the location of the charge. In Faraday's field concept, it is the electric field of one charged entity that pushes or pulls on the electric field of another. If the fields are unlike each other, they will attract each other. But as shown in Figure 2, if the fields are the same as each other, they will push against each other. However, as the distance from a charged entity increases, its electric field is distributed over a greater area. Thus, its force is diminished. Because the field expands outward from the charged particle equally in all directions, the area over which it is spread at a distance r is equal to the area of a sphere whose radius is r. The equation for the area of a sphere is:

$$A = 4\pi r^2$$

Thus, if an entity whose electric charge is Q has an electric field E when measured directly at its location in space, the strength (or amount) of electric field E_r measured at a distance r should be equal to E divided by the area of a sphere with radius r. However, what will be measured at that distance is not what one would expect from the increased area over which the field is spread. Instead of being equal to E divided by $4\pi r^2$, the value of E_r is proportional to the expected result but not equal to it.

$E_r \propto \frac{E}{A}$ And $A = 4\pi r^2$, which means

$$E_r \propto \frac{E}{4\pi r^2} \quad \text{Proportionality 1}$$

Why is E_r merely proportional to E divided by $4\pi r^2$ rather than being equal to it? The only difference between them is that E is measured at the source and E_r is measured at the distance r from the source. That spreads E over a larger area; the area of a sphere with radius r and a surface area of $4\pi r^2$. What else is going on?

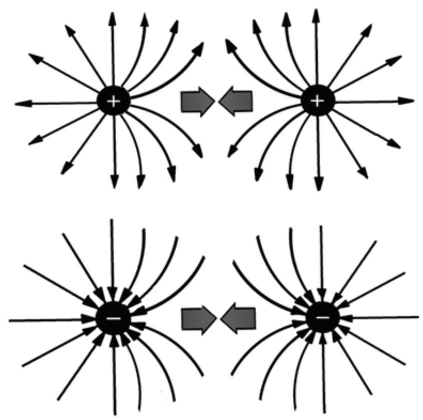
As it happens, the French physicist Charles Coulomb made extensive experiments of the interactions between charged entities in the 1780s. The results of his experiments are expressed in Coulomb's law for the amount of electric field E_r resulting from a single point charge Q at a distance r:

$$E_r = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2} \quad \text{Equation 2 (Coulomb's law)}$$ [ix]

We can rearrange Coulomb's law for comparison with Proportionality 1 as follows:

FIGURE 2

LIKE ELECTRIC FIELDS REPEL EACH OTHER



$$E_r = \frac{Q}{4\pi r^2}\frac{1}{\epsilon_0} \quad \text{(another form of Coulomb's law)}$$

Equation 3

Comparing Equation 3 with Proportionality 1, we can see that this is exactly what we would expect at distance r, [x] except that we must include that same constant ϵ_0 that we found in Maxwell's first equation to get from proportionality to equality. Comparing Equation 3 with Maxwell's first equation shows that the density of an electric charge (ρ_{EC}) at a distance (r) from its source is equal to the charge at its source Q adjusted for the area over which it is spread at that distance:

$$\rho_{EC} = \frac{Q}{4\pi r^2}$$

Substituting this value for ρ_{EC} in Maxwell's first equation produces the same equation as Coulomb's law.

$$\underbrace{\nabla \cdot E = \frac{\rho_{EC}}{\epsilon_0}}_{\text{Maxwell's first equation}} = \frac{Q/4\pi r^2}{\epsilon_0} = \underbrace{\frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}}_{\text{Coulomb's law}} \quad \text{Equation 4}$$

Maxwell's first equation and Coulomb's law are two ways of saying the same thing. $\nabla \cdot E$, in Maxwell's first equation, is just another way to say E_r, except it goes on to say that the amount of electric field is *coming from* the density of the electric charge at that location rather than merely being equal to it. The difference between "coming from" and "equal to" reflects Maxwell's intuition that the force applied by an electric field is dynamic. There is something more involved than simply being present. (e.g., A teacher must do more than merely be present to pass knowledge to students. There must be some form of interaction as well.)

Why did we go through this? To show that Maxwell's first equation, taken in context with Coulomb's law, tells us two important things. First, the force of a point charge's electric field spreads out equally in all directions. Thus, it will diminish with distance at a rate which is proportional to the increase in the area over which it is spread. Second, something additional is going on that is related to the constant, ϵ_0. Clearly, ϵ_0 has something to do with the fact that an electric field must act dynamically in order to be expressed. It can't express itself merely by being present.

Now let's see what we can learn from Maxwell's second equation:

$$\nabla \cdot B = 0.$$

$\nabla \cdot B$ stands for the amount of *magnetic* field B coming from a location in space. The equation tells us that it is equal to … zero? Actually, what that means is that magnetic fields don't come from a point charge that has a location in space. Wherever you find a magnetic field the whole field is present and accounted for. Magnetic fields always go around in loops. They don't have a beginning or an end. (Note that the symbol B in this equation stands for the magnetic field and not for a bulk modulus. Every use of B for a bulk modulus in this report has a subscript to denote the medium to which it belongs.)

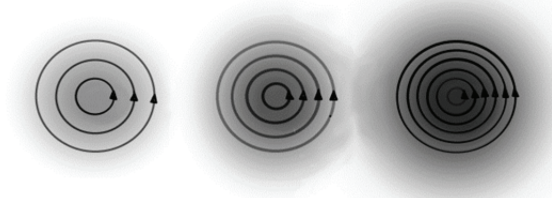
Maxwell's third equation:

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

tells us that there is another source for an electric field beyond the one described in Maxwell's first equation. The electric field described in Maxwell's first equation comes from an electrically charged entity that exists at a point in space. This electric field is caused by the movement of a magnetic field. What we need to know here is that the symbol $\nabla \times E$ stands for the curl of the electric field. The term "curl" here means just what it says. *This* electric field goes around in loops, just like the magnetic field always does. $\nabla \times E$ is minus the rate of change of the magnetic field $\partial B/\partial t$. (The minus just means that E curls in the opposite direction from B.) As shown in Figure 3, increasing the amount of curl means reducing the radius of the arc. Thus, the curlier the field, the tighter its circles are wrapped around each other and the greater is the field's density. This simply means that the faster the magnetic field changes, the denser is the electric field it creates. The denser the field, the more energy it has packed into it and the greater the strength of its compulsion to dissipate and of its opposition to further compression. That is the same behavior as that of air. The more densely the air is compressed, the harder it pushes to expand and the harder it is to compress.

FIGURE 3

MORE CURL MEANS TIGHTER LOOPS
TIGHTER LOOPS MEANS GREATER FIELD DENSITY
GREATER DENSITY MEANS STRONGER FORCE OF REPULSION



Maxwell's fourth equation:

$$\nabla \times B = \mu_0 J + \mu_0 \epsilon_0 \frac{\partial E}{\partial t}$$

says that the curl (field density, field strength) of the magnetic field is determined by the sum of two things, both of them related to the movement of electric fields. The first is the density (amount) of an electric current J multiplied by another constant μ_0. The second is the rate of change in the electric field ($\partial E/\partial t$) multiplied by both constants μ_0 and ϵ_0. The specific values of those two constants were determined by what they had to be to make the results of the equations match the values observed in the experiments. As it turned out, they had quite a story to tell.

That story begins with Maxwell's recognition that his fourth equation shows you can have a magnetic field without having an electric current. If you set J to zero, his fourth equation effectively becomes:

$$\nabla \times B = \mu_0 \epsilon_0 \frac{\partial E}{\partial t} \qquad \text{Equation 5}$$

No current is present, but we have a magnetic field as long as there is a changing electric field. And remember that Maxwell's third equation shows that all you need in order to have an electric field is a changing magnetic field. Both the electric and magnetic fields are curled into loops rather than emanating outward from a point source. Because each type of field in motion creates the other, they can go on supporting mutual creation indefinitely. (We call it electromagnetic radiation.)[xi]

Taking his third equation and his fourth equation with J set to zero (Equation 5), Maxwell developed two more equations that tell us how the electric and magnetic fields move in space as a result of their change in time:

$$\nabla^2 E = -\mu_0 \epsilon_0 \frac{\partial^2 E}{\partial t^2} \quad \text{Equation 6}$$

$$\nabla^2 B = -\mu_0 \epsilon_0 \frac{\partial^2 B}{\partial t^2} \quad \text{Equation 7}$$

On the right hand side of each equation is the change in the field's rate of change in time and on the left hand side is the change in the same type of field's rate of change in space. An electromagnetic wave's speed of propagation turns out to be dependent on the values of μ_0 and ϵ_0. Maxwell solved these differential equations to determine that speed as:

$$v = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

When he plugged the experimentally derived values for μ_0 and ϵ_0 into this equation, the value of v turned out to be the same as the previously determined speed of light. This is how Maxwell discovered that light is an electromagnetic wave. Since the speed of light in empty space always is precisely the same, it has been assigned its own symbol c and the equation for its speed is

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

Note that this equation also says that the speed in the vacuum of empty space of every electromagnetic wave, regardless of wavelength, frequency or amplitude, is precisely the same. Also, because the equation contains only two empirically derived constants, this also strongly (but incorrectly) suggests that the speed of light (in its broad sense as the speed of all electromagnetic waves) is independent of physical laws. After all, a constant is just a constant.

This segue through Maxwell's equations was made to develop an understanding of how the determinants of the speed of light compare with those of the speed of sound. But before we do that, it's worth noting some of the implications and interpretations about electromagnetism that have resulted from the structure of Maxwell's equations.

First, the structures of Equations 6 and 7 are identical. $\nabla^2 \square = -\mu_0 \epsilon_0 \frac{\partial^2 \square}{\partial t^2}$

If you put the electric field in the box on the right, you get the rate of change of the electric field's rate of displacement in space on the left. If you put the magnetic field in the box on the right, you get the rate of change of the magnetic field's rate of displacement in space on the left. This appears to have caused a perception that electric and magnetic fields might be coequal. There have been several attempts to identify a magnetic monopole, so far without success. However, this coequality is only apparent, not real. An electric field can exist in the absence of a magnetic field. Its original source is a charged particle (Maxwell's first equation). A magnetic field exists only when being created by an electric field in motion. The appearance of equality comes from having removed the electric current (*J*) from Maxwell's fourth equation (producing Equation 5) before developing Equations 6 and 7. When the electric current is removed, the electric field is reduced to the same dependency on the magnetic field as the magnetic field always has on the electric field. Once an electromagnetic wave leaves its source, the only electric field it contains is a loop-shaped (not point-sourced) electric field created by a moving magnetic field. This co-dependency between the motions of the two fields *in an electromagnetic wave* is why it can be said that when a photon stops moving it ceases to exist.

Another interpretational problem that arises from the structure of equations 6 and 7 is that each field's change in displacement is described in terms of its own change in time. That implies, incorrectly, that each field somehow moves itself through empty space. That, in turn, omits something really important that happens in between. An electric field that changes in time does not directly create an electric field that moves in space. According to Equation 5, what it does is create a magnetic field. According to Maxwell's third equation, that magnetic field's motion then creates the next electric field. Once begun, this interaction between the two types of field will continue until interrupted by an outside force. By failing to express these essential interim steps, equations 6 and 7 lull us into thinking that the medium of propagation is the vacuum of free space. Not so. The medium of propagation for the moving electric field is the magnetic field it must push into existence as an unavoidable consequence of its movement. The magnetic field starts with zero density (it doesn't yet exist) and moves to greater density as the moving electric field pushes and curls it into existence. It is in the nature of the magnetic field to resist having its density increased. Just like air, *the magnetic field being pushed into existence has both a density and an innate resistance to being compressed (a.k.a. a bulk modulus). It is inarguable that the magnetic field is acting as the medium of propagation for the electric field. It is actively created by the motion of the electric field and it is the only active element in the creation of the next electric field. The same is true of the electric field's characteristics and its actions to propagate the magnetic field*.[xii] The same phenomena are at work in a similar manner for the propagation of light as for the propagation of sound. A disturbance in the electric field's density initiates an ongoing interaction between its compulsion to expand at one area in space and the magnetic field's opposition to compression in the adjacent area in space. The magnetic field, being on the opposite side from the electric field on each transaction, takes turns in performing the same functions for the electric field as the electric field performs for the magnetic field. In the case of sound, there is only one medium on both sides of the interaction between the medium's compulsion to expand and its opposition to compression. Light has two mediums. Whichever field is dominant (i.e., the more powerfully compressed) can decompress only by overcoming the other field's resistance to compression. The electric and magnetic fields simply take turns as they work their alternate sides of the transaction.

What we failed to realize when we accepted μ_0 and ϵ_0 as simple constants, derived to make the equations meet the observations, is their underlying physical significance.[xiii] ϵ_0 is not the "permittivity of free space." It has nothing to do with the characteristics of space. It is determined by how hard an electric field pushes against itself. That, in turn, determines how fast it will move, in order to decompress, when its motion is unopposed. Even when its motion is unopposed, that speed of decompression is not infinite. It is a function of the strength of the innate force of repulsion of like electric fields (a.k.a. a function of the electric field's bulk modulus). The same is true of μ_0 for a magnetic field. This will be explained more fully in Section 4. But before we do that, we must become more familiar with the mechanics of how air's response to a sound wave causes it to act as the medium of propagation for sound. The equation for the speed of sound tells us *what* determines the speed of sound, but does not explain *how* it determines the speed of sound.

3. DISSECTING THE EQUATION FOR THE SPEED OF SOUND

On the surface, the equations for the speed of sound and the speed of light are totally different from each other. Using v_s as the symbol for the speed of sound, the equation for the speed of sound is:

$$v_s = \sqrt{\frac{B_a}{\rho_a}} \qquad \text{Equation 8 [xiv]}$$

In the equation, B_a stands for the bulk modulus of air and ρ_a stands for its density. The bulk modulus describes air's innate compulsion to expand and, on the other side of the same coin, its innate resistance to compression. The formula for air's bulk modulus is:

$$B_a = -\frac{\Delta p}{\Delta V/V_0} \qquad \text{Equation 9 [xv]}$$

As shown in Equation 9, the value of B_a is determined by the change in pressure Δp that is required to reduce the volume by a given amount ΔV relative to the initial volume V_0. (The minus sign just means that the pressure and volume change in opposite directions. When pressure is increased, volume is reduced, and vice versa. The result is always a positive number for B_a). The more pressure that is required to produce a given reduction in volume (i.e., the harder it is to compress the medium), the greater the value of B_a and, as shown in Equation 8, the faster the wave will move. ρ_a is the density of air. The greater the density, the slower the wave will move. These two characteristics of air are what determine the speed of sound. However, to compare Equation 8 with the equation for the speed of light, it will be necessary to look inside it for more information. So … get out the scalpel.

Instead of focusing on what the speed of sound v_s is equal to in equation 8, one must focus on what B_a/ρ_a is equal to.

$$\frac{B_a}{\rho_a} = {v_s}^2 \qquad \text{Equation 10}$$

Looking at it that way raises an interesting question: Why is the ratio of air's compressive-resistance B_a to its density ρ_a equal to the *square* of the speed of sound v_s? Why isn't it directly equal to the speed of sound? What is going on inside of B_a/ρ_a that makes it equal to v_s^2? Note that the standard equation for velocity is

$$v = \frac{d}{t} \qquad \text{Equation 11}$$

Velocity is defined in terms of distance traveled per unit of time. Thus, if $B_a/\rho_a = v_s^2$, one also must conclude that:

$$\frac{B_a}{\rho_a} = (d/t)^2 = \frac{d}{t}\frac{d}{t} \quad \text{Equation 12}$$

Thus, the ratio of B_a to ρ_a can be considered as being equal to the product of two velocities. However, one must take care not to fall into the trap of an implicit assumption. In order for v_s to be equal to the square root of B_a/ρ_a it is not necessary for the two velocities whose product is equal to B_a/ρ_a to each be equal to v_s. For example, suppose there are two velocities $v_1 = d_1/t$ and $v_2 = d_2/t$.

$$\text{If} \quad \frac{d_1}{t}\frac{d_2}{t} = \frac{B_a}{\rho_a} \quad \text{then} \quad v_s = \sqrt{\frac{B_a}{\rho_a}} = \sqrt{\frac{d_1}{t}\frac{d_2}{t}}$$

Equation 13

Thus, in order to more fully understand what determines the speed of sound one must understand the nature of the two velocities whose product is equal to the ratio of B_a to ρ_a. In order to do that, it will be useful to recognize that there are two ways of defining the rate of movement, one way is velocity and the other is its reciprocal.

$$v = \frac{d}{t} \quad \text{and its reciprocal} \quad \omega = \frac{1}{v} = \frac{t}{d}$$

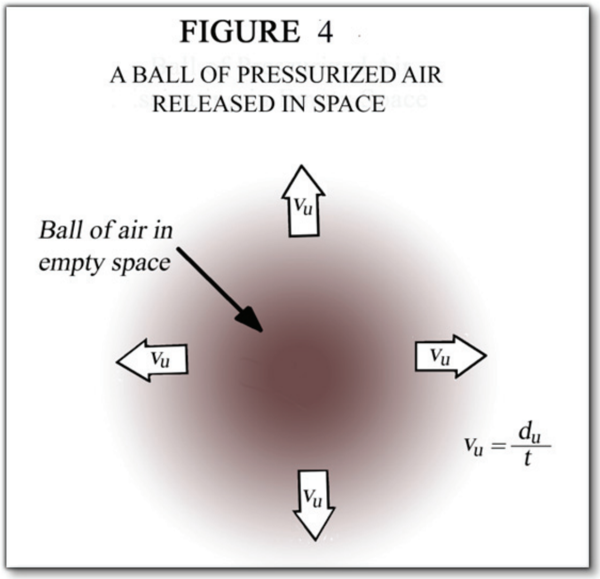
v and ω are simply two ways of saying the same thing. One way, velocity, focuses on the ratio of distance to time. The other focuses on the ratio of time to distance. The former is more easily recognized simply because we are almost always interested in how fast an identifiable object is moving. But for expressing the motion of something as amorphous as air pressure or the pressure of the self-repellence of like electric and like magnetic fields, the latter can be more useful. A pocket of pressurized air and an electric or magnetic field exist over an area. If the field is in motion, the entire field is in motion. If one is measuring a field "coming from" somewhere (e.g., as in Maxwell's equations) then it is more useful to think of it as a rate of flow. The amount one receives of whatever is flowing to him is determined by how much stuff there is and how long it takes to be delivered. The time it takes to be delivered is the reciprocal of how fast it is moving.

A sound wave is simply a pocket of compressed air whose pressure moves through a sea of less compressed air. The molecules of air only move back and forth. It is the pocket of pressure which moves through the sea of air from source to listener. The movement of that pocket of pressure results from the interplay between the innate compulsion of the pressurized pocket of air to reduce its pressure by expanding and the innate resistance of the surrounding air to being compressed. To understand what happens, one must consider that it involves pressures on both sides of the transaction, each trying to create motion, but in opposite directions. The forces are pushing against each other. Either force, acting alone, would determine the velocity at which the air on its side of the transaction would move. Their net effect is to determine the speed at which the higher-pressure side expands at the expense of the other side. Whichever medium on one side of the traction is expanding, the medium on the other side is being compressed. Also, each medium's pressure to expand at any given level of compression is the same as its pressure to resist compression. The same forces are at work at the same level of intensity in both directions. Thus, one can think of rate at which a domain of medium can expand as being the same as the rate by which it can oppose compression.

The first velocity to address for the propagation of sound is the speed at which a pressurized domain of air can expand to relieve its pressure when its expansion is unopposed. As shown in Figure 4, if a ball of pressurized air were to be released instantly in empty space, it would be free to expand outward in all directions without anything to constrain it. The speed at which it can expand is determined only by the innate intensity of its self-opposition. One can define that speed as the maximum rate at which the air pressure can expand when unopposed. Its rate of motion can be expressed either as its velocity or how long it takes for it to move.

$$v_u = \frac{d_u}{t} \quad \text{or} \quad \omega_u = \frac{t_u}{d}$$

We don't have to know the precise magnitude of v_u to understand the function it plays in determining the speed of sound. We know its value is a constant which is greater than zero and smaller than infinity. Otherwise, the speed of sound would be either zero or infinite. We also know from equation 12 that the square root of its product with another velocity (one which acts as an environmental constraint) determines the speed of sound. That is all we need to know to understand its function in determining the speed of sound.



When the pocket of pressurized air is a sound wave on Earth, it will be surrounded by ambient air. Thus, the other source of velocity is encountered in the form of a constraint; the resistance to compression of the ambient air. But as discussed above, the intensity to expand for any given domain of medium is identical to the intensity with which it opposes compression. If a pocket of the ambient air were suddenly released in empty space, the velocity at which it would expand would be:

$$v_o = \frac{d_o}{t}$$

But since the ambient air acts as a constraint on the sound wave's expansion, it is best understood in the time constraint form of the motion ω.

$$\omega_o = \frac{1}{v_0} = \frac{t}{d_0}$$

ω_o is the time delay in the rate of expansion of the pressurized air (a.k.a. the sound wave) due to the resistance to compression of the ambient air surrounding it (a.k.a. the sound wave's medium of propagation). The interaction of these two opposing rates of motion ω_u and ω_o is what determines the speed of sound. We know from Equation 12 that the product of their reciprocals is equal to B_a/ρ_a and we know from Equation 8 that the square root of the product of their reciprocals is equal to the speed of sound.

To facilitate comparing the equation for the speed of sound with the equation for the speed of light, both velocities will be expressed in their "time constraint" form $\omega = t/d$ in the expanded equation for the speed of sound. Returning to Equation 13, it can be rewritten as follows:

$$\frac{B_a}{\rho_a} = v_s^2 = v_u\, v_o = \frac{1}{\omega_u}\frac{1}{\omega_o} \quad \text{Equation 14}$$

Substituting that for B_a/ρ_a in Equation 8 gives:

$$v_s = \sqrt{\frac{B_a}{\rho_a}} = \sqrt{v_u v_o} = \sqrt{\frac{1}{\omega_u}\frac{1}{\omega_o}} = \frac{1}{\sqrt{\omega_u \omega_o}}$$

Equation 15 which can be shortened to:

$$v_s = \frac{1}{\sqrt{\omega_u \omega_o}}$$

Does that look familiar? Recall that the equation Maxwell developed for the speed of light is:

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

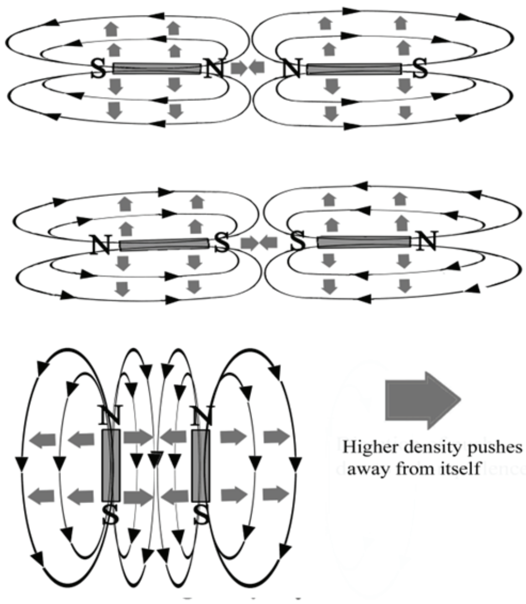
It now is time to look more closely inside the equation for the speed of light to examine the physical dynamics which determine the values of ϵ_0 and μ_0. ϵ_0 and μ_0 are not merely constants whose values were determined by experiment. Their values are determined by the strength of the innate forces of repulsion between like electric fields and between like magnetic fields. This is the same kind of innate response as that of air pressure's innate compulsion to push away from itself.

4. DISSECTING THE EQUATION FOR THE SPEED OF LIGHT

As previously shown in Figure 2, like electric fields innately repel each other. That is why electrons repel other electrons and protons repel other protons. As shown in Figure 5, the same is true of like magnetic fields. That is why a magnet resists having its north pole pushed against the north pole of another and also resists having its south pole pushed against the south pole of another. Even when the magnets are placed side by side, they resist being pushed together as long as their field lines are oriented in the same direction (i.e., are like each other).

FIGURE A-5

LIKE MAGNETIC FIELDS REPEL EACH OTHER



The gray arrows show the effect of two sources of repulsion which push the magnets apart. The magnetic fields around each magnet are doing two things simultaneously. They are pushing themselves away from their greatest density inside the magnet (they are like fields to themselves) and also are pushing against the like field of the other magnet.

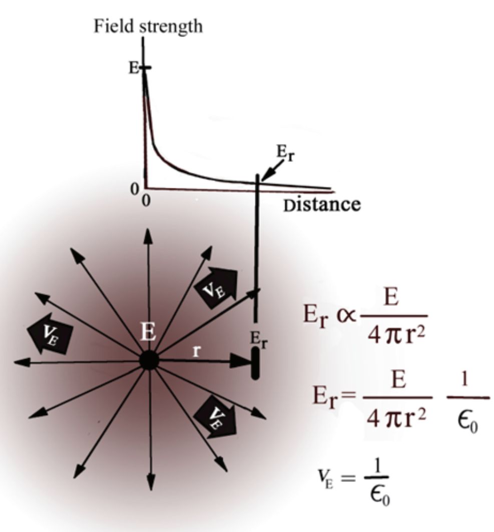
This innate force of repulsion between like energy fields is analogous to the innate force of repulsion between molecules of air. It causes a domain of like energy field to push away from itself, internally, (compulsion to expand) and push away from another like field externally (resistance to compression). As described for the speed of sound, the pocket of air pressure (i.e., the wave) pushes away from itself internally while it simultaneously pushes against the external pressure of the ambient air. It is the innate intensity of the force of self-repulsion which determines the speed of the wave.

A useful concept for understanding the nature of electric and magnetic fields is to consider them as dense, self-repelling, three-dimensional clouds surrounding their source. For example, as shown in Figure 6, the field surrounding an electron can be considered as a dense cloud of energy whose intensity diminishes with distance as it pushes itself away in all directions from the electron. It's analogous to the pocket of pressurized air in empty space. As one travels outward along any field line directly away from the source, the field's density diminishes at a rate proportional to $1/4\pi r^2$.

But as shown in Coulomb's law (Equation 2) and in Maxwell's first equation, the measured field strength at a distance r from its source also is affected by whatever causes the value of ϵ_0. The benefit of picturing the field as being like a pocket of pressure is that it makes it clear that the innate force of

FIGURE 6

AN ELECTRIC FIELD DIMINISHES WITH DISTANCE AT A RATE PROPORTIONAL TO $1/4\pi r^2$



repulsion between like fields operates both within the isolated electron's field as well as against the field of another electron. The greater field density at the source pushes the field outward. When the field is isolated and stationary, there is nothing to interfere with the field's expansion. As with the air's pressure in empty space (Figure 4) that is the condition under which the field can push itself away from itself at the greatest rate. However, there still is an experimentally determined impediment ϵ_0 to its availability at the point of measurement (i.e., at the distance r from its source). Not knowing what might cause that impediment, and thinking of the energy as moving through empty space, Coulomb attributed it to some innate characteristic of empty space. Hence, it was identified as the "permittivity of space" [xvi] However, just as the value of ω_u is determined by the rate at which air pressure can dissipate, when unopposed in empty space (Figure 4), the value of ϵ_0 determined by the innate rate at which like electric fields can dissipate when unopposed in empty space. The innate level of self-repulsion of like electric fields can be defined as the innate intensity at which adjacent parts of the field push away from each other at a given level of density (i.e., its bulk modulus). This can be expressed both in terms of velocity and in terms of its reciprocal.

$$v_E = \frac{d_E}{t} \quad \text{and its reciprocal} \quad \epsilon_0 = \frac{1}{v_E} = \frac{t}{d_E}$$

Recall that v_E and ϵ_0 are just two ways of expressing the same thing; the innate rate at which like electric fields can push away from each other. That innate level of self repulsion is what drives both the compulsion to dissipate and the resistance to being compressed. Just as with the innate rate at which air pressure can expand, we can know that the values of v_E and ϵ_0 are constants between zero and infinity since the speed of light is neither zero nor infinite. (We are not concerned with their specific values at this point. The value of ϵ_0 already has been determined by Coulomb. What we are doing here is getting familiar with what ϵ_0 is and how it works.)

As shown in Figure 7, the innate self-repulsion of like magnetic fields operates in the same manner as that of like electric fields. Thus, the innate rate at which a magnetic field can push away from itself when not being opposed by an outside force can be expressed as:

$$v_B = \frac{d_B}{t} \quad \text{and its reciprocal} \quad \mu_0 = \frac{1}{v_B} = \frac{t}{d_B}$$

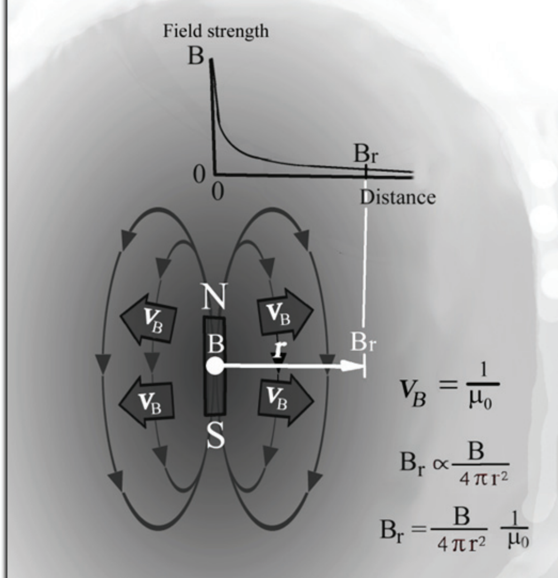
Again, v_B and μ_0 both are ways to express the innate rate at which like magnetic fields can push away from each other.

Now we are at the key difference between a single medium, which possesses all five of the characteristics assumed to be present in any medium of propagation, and the two mediums for light which possesses only the fifth characteristic. (Ironically, that is the only one Michelson and Morely didn't look for.) Recall that in Equation 15, the speed at which air pressure can dissipate when unopposed v_u is being retarded by the innate resistance of the ambient air to being compressed. Thus, the speed v_o at which the ambient air would dissipate, from its own internal forces, is working in opposition to v_u. As shown in Equation 15, the net effect of the two forces in opposition to each other is equal to the square root of the product of their reciprocals. However, in the case of light, there are two different mediums opposing each other from opposite sides of the interaction. Whichever one is expanding (uncurling) can do so only by compressing (curling) the other.

What are the conditions of being opposed versus unopposed with respect to the movement of electric and magnetic fields? Maxwell's equations tell us that a field's movement to dissipate its intensity is unopposed when the field, itself, is not in motion. What that means is that the field and its field lines all are stationary. The field's intensity spreads out along the stationary field lines. That is akin to the pocket of pressurized air released in empty space where there is no opposition to its expansion by surrounding ambient air. But, as shown in Maxwell's third and fourth equations, when either type of field is in motion (i.e., the field itself and its field lines are in motion), it must create and curl the other type of field. As previously noted in Figure 3, increasing the

FIGURE 7

A MAGNETIC FIELD DIMINISHES WITH DISTANCE AT A RATE PROPORTIONAL TO $1/4\pi r^2$



curl of a looped field means reducing the radius of its field lines. That tightens the loops and increases the field's density. It is in the nature of both electric and magnetic fields to oppose having their density increased. The interaction between the two types of field consists of the compulsion of the field on one side to dissipate (uncurl) and the compulsion of the field on the other side to resist being curled. This is identical to the dynamic interaction between the pocket of compressed air and the pressure of the surrounding ambient air which both propagates the pocket of pressure (the sound wave) and determines its speed. The only difference is that with sound, the same medium (air) is both stationary and physically present on both sides of the transaction. In the case of light, the electric and magnetic fields take turns on opposite sides of the transaction as they push each other and the wave through space and travel along with it.

Wave	Equation	Analytical Insights	Structural Comparison
Sound	$v_s = \sqrt{\frac{B_a}{\rho_a}}$	$\frac{B_a}{\rho_a} = v_s^2 = v_u v_o$; $v_u = \frac{1}{\omega_u}$; $v_o = \frac{1}{\omega_o}$	$v_s = \sqrt{\frac{B_a}{\rho_a}} = \sqrt{v_u v_o} = \sqrt{\frac{1}{\omega_u}\frac{1}{\omega_o}} = \frac{1}{\sqrt{\omega_u \omega_0}}$
Light	$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$	$c^2 = \frac{1}{\epsilon_0}\frac{1}{\mu_0}$; $\frac{1}{\epsilon_0} = v_E$; $\frac{1}{\mu_0} = v_B$	$c = \sqrt{v_E v_B} = \sqrt{\frac{1}{\epsilon_0}\frac{1}{\mu_0}} = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$

5. SUMMARY AND CONCLUSIONS

Having dissected the equations for the speed of sound and the speed of light, a more informed comparison now can be made between them.

Light and sound both are propagated by the innate physical behavior of their respective mediums of propagation. The behavior of the mediums of propagation, both for light waves and sound waves, is determined by their respective innate characteristics of self-repulsion. This characteristic both creates an innate compulsion for the medium to expand and an innate resistance to being compressed. It is the strength of these innate drives, which are inherent in the natures of the respective mediums, which causes the waves to propagate and which determines their respective speeds.

The propagation of light differs from that of sound and other waves in that, for light, the mediums and the wave are the same entities. (Or as the author's colleague Dr. Raymond Gallucci observed, paraphrasing Marshall McLuhan, the medium is the message.) For other waves, the medium is physically separate from the wave. Thus, for other waves, the medium is present whether the wave is propagating through it or not. The medium must be found wherever the wave is able to go. The medium is stationary and pushes the wave through it. The only thing light waves have in common with other waves is that their propagation is determined by the innate self-repelling characteristics of their respective mediums of propagation.

The reason why light can propagate through empty space is because the motions of its constituent electric and magnetic fields, once started, both create each other and push each other through space. Thus, there is no need for a stationary medium. They also don't need to permeate space because they always are right there where they are needed to push the wave. Indeed, they are the wave. The light wave and the mediums, being the same entities, travel together. Rather than being stationary, the mediums for light move at the same speed as the wave. Thus, certain characteristics of motion, such as the Doppler Effect, may not always operate in the same manner for light as for waves in stationary physical mediums.

The reason the speed of light is absolutely constant in empty space is not due to some kind of magical attribute of either space or light. It is because the characteristics of empty space are precisely the same wherever space is empty. There is nothing to interfere with or alter the innate behavior of electric and magnetic fields as they dance with each other in empty space. Wherever something interferes with the light, such as a dense cloud of cosmic dust, we say that area of space isn't empty. The same is true when light propagates itself through dense optical matter such as a lens or a prism. Contrary to popular belief, the optical matter doesn't act as a medium of propagation. The electric and magnetic fields of the charged particles in the glass randomly tug on the electric and magnetic fields in the light as it transits through the glass. The resulting meandering path averages out to the same trajectory but slows its forward propagation. That, in turn, causes the light's electromagnetic waves to refract.

In the case of sound, there are numerous climate and weather conditions that can alter the innate characteristics of ambient air. Temperature, altitude, humidity, high and low pressure areas, and wind are but a few. Similar sources of variability exist for all known waves, other than light, all of which propagate through mediums comprised of physical matter. Thus it is common to think of the speeds of waves as being innately variable. However, there is no basis for expecting the speed of light in empty space to be anything but constant. That isn't magic. It's simply the laws of physics at work in the constant, uniform environment of empty space.

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[i] Douglas G Giancoli, *Physics*, 4th edition (Englewood Cliffs, New Jersey: Prentice Hall, 1995), 750-751

[ii] Cox, *Why does E=*MC^2*,* 29: "Most, if not all, of the scientists of the time believed that all waves, including light, must travel in some kind of medium; there must be some 'real stuff' that is doing the waving."
Giancoli, *Physics,*745: "Nineteenth-century physicists viewed the material world in terms of the laws of mechanics, so it was natural for them to assume that light, too, must travel in some medium."
Perkowitz, *Empire of Light*, 64: "The properties of this supposed medium, called the ether, could be surmised before it was found. Like any material, it could be modeled as a collection of connected atoms."

[iii] Cox, *Why Does E=*MC^2, 29: "It must permeate all of space, since light travels across the voids between the sun and earth and the distant stars and galaxies."
Giancoli, *Physics,* 745: "They called this transparent medium the ether and assumed it permeated all space."
Perkowitz, *Empire of Light*, 65: "It seemed undeniable that only a taut, resilient ether could sustain light's speed and enormous vibrational rate. But surely such a medium would be tangible as it filled all space?"

[iv]Given that any medium of propagation was accepted as being physically separate from the wave (endnote ii) and as being present throughout the domain in which the wave can propagate (endnote iii), the medium also must be there whether or not a wave happens to be propagating through it.

[v] Cox, *Why Does E=*MC^2, 29: "The speed that appeared in Maxwell's equations then had a very natural interpretation as the speed of light relative to the ether. This is exactly analogous to the propagation of sound waves through air."
Giancoli, *Physics,* 745: "It was therefore assumed that the velocity of light given by Maxwell's equations must be with respect to the ether."
Perkowitz, *Empire of Light,* 64-65: "In hard, resilient stuff, like steel, the atoms are tightly linked to one another. Energy moves quickly from atom to atom. By contrast, waves move more slowly among the loosely joined atoms of a soft gelatinous substance."

[vi] Cox, *Why Does E=*MC^2, 29: "This is exactly analogous to the propagation of sound through air. If the air is at a fixed temperature and pressure, then sound always will travel at a constant speed, which depends only on the details of the interactions between the air molecules …"
Perkowitz, *Empire of Light,* 64-65**:** "The properties of this supposed medium, called the ether, could be surmised before it was found. Like any material, it could be modeled as a collection of connected atoms. In hard resilient stuff like steel, atoms are tightly linked to one another. Energy passes quickly from atom to atom, so that any waves generated in the medium oscillate rapidly and travel at high speed. By contrast, waves move more slowly among the loosely joined atoms of a soft, gelatinous substance. … It seemed undeniable that only a taut, resilient ether could sustain light's high speed and enormous vibrational rate. Somehow, the ether was firmer and more elastic than steel, yet completely penetrable. … Physicists expended great ingenuity in seeking an ether with the right characteristics, even imagining new forms of matter with the proper contradictory qualities."

[vii] The material describing Maxwell's equations presented here is excerpted from the author's book Calkins, Richard O., *Relativity Revisited* (Sammamish, Washington: A Different Perception, 2011), 14-20. For his understanding of Maxwell's equations, the author owes a great debt of gratitude to David Morgan-Mar for his excellent dissertation on Maxwell's equations in his humorous and insightful blog www.irregularwebcomic.net/1420.html, as modified December 16, 2006. Any errors in explaining the meaning and implications of the equations are the author's own. The author also owes a debt of gratitude to Ray Gallucci, PhD, PE for identifying an error in the author's interpretation of ϵ_0 and μ_0 in *Relativity Revisited* which has been corrected here.

[viii] The subscript (EC) is added to the density symbol ρ to identify it as the density of the electric charge. This is to avoid confusion with other density parameters used later.

[ix] Giancoli, *Physics,* 465 (The subscript *r* was added to *E* in the equation for Coulomb's law for symbol consistency with Proportionality 1).

[x] Note that in Proportionality 1, we took the electric field E at the location of its point source and then made the adjustment for distance r. Coulomb's law adjusts the amount of the charge Q for the effect of distance r before measuring its field. Mathematically, these are just two different ways to get to the same result.

[xi] Giancoli, *Physics,* 628.

[xii] In other words, each of the two types of field is the medium of propagation for the other.

[xiii] The role ϵ_0 and μ_0 play in determining the speed of light has interesting implications regarding what information may be hidden in other proportionality constants. For example, does the universal gravitational constant (G) in Newton's Law of Universal Gravitation tell us something about the speed of gravitational waves?

[xiv] Giancoli, *Physics,* 314.

[xv]Ibid.

[xvi] Ibid., 461.