Planck's Constant and the Nature of Light

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Planck's constant, h, is a central character in light theory and quantum mechanics and is traditionally referred to as the quantum of action. The classical definition of action is "kinetic energy minus potential energy, multiplied by time", with units [J s]. The units of the energy equation, $E = hf$, are traditionally written as [J s 1/s] where units of frequency, f, are [1/s] (cycles per second or Hertz), and the units of Planck's constant, h, are [J s], or the units of action. The two [s] units of this energy equation cancel and the units of $E = hf$ reduce to [J] as expected. Or do they? Using Modified Unit Analysis (MUA), it is shown that the units [J s 1/s] are not exactly equal to [J], leading to a flaw in the logic of the standard interpretation of light. Using the MUA approach, the numerical value of Planck's constant is seen as the energy of one oscillation (one wavelength, one period) of an electromagnetic wave with frequency f. This reinterpretation of Planck's energy equation leads to a much simpler interpretation of light which can be modeled using the same mathematical construct ($e^{i\phi} = cos(\phi) + isin(\phi)$) as all other oscillating wave phenomenon.

Keywords: Planck's constant, unit analysis, domain, wavelength, frequency, period, cycle, wavefunction, sine, cosine, photon, action, energy, uncertainty principle, luminosity, capacitance, inductance, Maxwell

1. Introduction

Planck's constant, h, named after the physicist Max Planck, is an important fundamental quantity in quantum physics. It links the amount of energy that a "photon" carries to the frequency of its electromagnetic wave. The inputs of Planck's energy equation, $E = hf$, are action [J s] and frequency [1/s] and the output, E, interprets as the energy of one photon with units [J]. Photons are literally defined as fundamental particles, but what does this mean? Electrons are fundamental particles because all electrons contain the same mass-energy. Protons are also fundamental particles since all protons contain the same mass-energy. Photons on the other hand, can take on many energies, so how can they be fundamental? Here are the questions we should be asking. What is a photon? How much time does it take to generate a photon? What is the energy of one oscillation of light? And finally, if the frequency is variable and the wavelength is variable and the photon energy is variable, then what does the constant, h, correspond to?

The purpose of this article is to convince the reader, beyond a reasonable doubt, that (the numerical value of) Planck's constant is the energy of one oscillation of light, no matter what frequency we are investigating. Although this appears to be a challenge to standard thinking, and it is, once you finish reading this article, you will have no choice but to conclude that the constant, 6.626×10^{-34}, is the energy of one oscillation (i.e., one period or one wavelength) of electromagnetic energy and interprets as the quantum of energy, h_Δ.

The problem seems to have arisen from an improper treatment of the units of frequency. Historically, and by convention, the units of frequency were defined as [1/s] or Hertz. I'm sure this seemed reasonable at the time, but here's the problem. The numerical value of [1] in the unit section of an equation is ambiguous. One what? Everyone knows that it corresponds to 1-cycle but it is not obvious at first glance. The SI unit of time is 1-second. The unit of time has its own label [s]. This is because time itself is its own domain, separate from the domains of space, mass and charge.

Although unit analysis generally goes by the name "dimensional analysis", the term "dimensional" is also ambiguous (it has many meanings). Unit analysis is better thought of as "domain analysis". In SI units, the unit of the Domain of Time is 1-second, [s]; the unit of the Domain of Space is 1-meter, [m]; the unit of the Domain of Mass is 1-kilogram, [kg]; the unit of the Domain of Charge is 1-Coulomb, [C].

In Modified Unit Analysis or MUA, as outlined in a previous paper by the author [2], the Domain of Cycles (a.k.a. Domain of Oscillation) is added as a unique domain of the system (separate from all the other domains). The unit of the Domain of Cycles is 1-cycle and and is assigned the unique label [Δ]. When this new label is applied to the unit of frequency, [Δ/s], a different picture of Planck's energy equation emerges. This simple change, Δ, to the language of unit analysis, changes more than just the interpretation of Planck's energy equation. It changes everything, as you will see.

By convention, in this article, all units are placed within square brackets to clearly distinguish the unit section of an equation from the main body of the equation.

2. The Energy Equation for Light

The energy equation for the photon is traditionally and by convention written as follows:

$$E = hf \left[J\ s \frac{1}{s}\right] \tag{1}$$

Here, E is the energy of the photon, h is non-reduced Planck's constant and f is the frequency of the photon in Hz. Planck's constant, h has units [J s] and frequency has units [1/s]. Using Modified Unit Analysis (MUA), the unit [1] in the unit section is replaced with the unit of the Domain of Cycles, Δ, as follows:

$$E = hf \left[J\, s \frac{\Delta}{s}\right] \tag{2}$$

When written this way, it is clear to see that the units for this equation are not balanced. When the units of frequency are written as [1/s], it only appears as if the units balanced because the [1] in the unit section is being treated both as the unit of the Domain of Cycles and the unit of the real numbers. Technically though, [J x 1] is not equal to [J] because the [1] in the unit section stands for 1-cycle and thus [J x 1] means [J x 1-cycle] which is definitely not equal to [J]. This is a problem. There are several, equivalent ways to solve this problem. This first is as follows:

$$E = hf \left[J \frac{s}{\Delta} \frac{\Delta}{s}\right] \tag{3}$$

In this equation, [s/Δ] reads "seconds per cycle" and are the units for the period, T, of a wave with frequency f. In this case, Planck's constant, h, has units [J s/Δ] and literally interprets as the energy "of" one period of an electromagnetic wave. The new [Δ] unit could also be applied as follows:

$$E = h_\Delta t_m f \left[\frac{J}{\Delta} s \frac{\Delta}{s}\right] \tag{4}$$

In this setup, the units of Planck's constant are [J/Δ] and interpret as energy per cycle or quantum of energy, h_Δ. In this equation, measure-time, t_m is explicitly shown in the body of the equation. Technically speaking, we have decoupled the unit of time from the unit of action. The equation on the left of the unit section is now interpreted as the equation of an experiment. In this case, the experiment has to do with counting cycles. In the above equations, (3) and (4), the unit section reduces to the units of energy, [J], as required. Also, in both equations, Planck's constant is associated with one cycle, one oscillation, one period and/or one wavelength of an electromagnetic wave. This seems to imply that each oscillation or wave**length** of light carries the SAME energy, h_Δ, regardless of frequency, contrary to standard thinking. To further this line of thinking, the body of the equation is expanded as follows:

$$E = \frac{h}{1} t_m \frac{n}{t_m} \left[\frac{J}{\Delta} s \frac{\Delta}{s}\right] \tag{5}$$

In this setup, all of the terms in the unit section correspond to a term in the body of the equation. This gives us a complete look at the photon energy equation and associated units. Here, $h/1$ interprets as energy per cycle and n/t_m interprets as cycles per second. The anomaly here is the time parameter, t_m. There is no time parameter in the original photon energy equation. However, if we set t_m equal to exactly 1 (1-second) and assume that we don't have to write the "1's" in the body of the equation (because 1 is the unit of the real numbers), then we recover the original $E = hf$. Here, f is the number of cycles counted in exactly one second (i.e., $n/1 = f$).

Although the time parameter of an experiment, t_m, can generally be set to any duration of time, it looks like the measure-time variable in the photon energy equation was inadvertently hard coded to exactly 1-second and subsequently hidden. This implies that the output of this equation is the energy collected (transported, absorbed) in an arbitrary 1-second time interval and not the energy of an elementary particle, i.e., a photon, as previously thought.

The logic presented in this section also suggests that each oscillation (cycle, wavelength, period) of light "carries" the same quantity of energy, $h_\Delta[J/\Delta]$ no matter which frequency we observe. Although this is clearly contrary to standard thinking, this logic suggests a new way of interpreting the "photon" energy equation.

3. A Power Equation for Light

Richard Feynman once said, "There is always another way to say the same thing, that doesn't look at all like the way it was said before". There is in fact another way to demonstrate the flaw in the logic of the original interpretation of the "photon" energy equation. Here, we are going to ignore the equation and look at the unit section directly, using the notation of MUA:

$$[J] = \left[\frac{J}{\Delta} s \frac{\Delta}{s}\right] \tag{6}$$

Divide both sides by [s]:

$$\left[\frac{J}{s}\right] = \left[\frac{J}{\Delta} \frac{\Delta}{s}\right] \tag{7}$$

Here, we have completely gotten rid of the concept action since the units [J s] no longer appear in the unit section. Now, we are going to write the equation that corresponds to these units as follows:

$$P = h_\Delta f = \left[\frac{J}{\Delta} \frac{\Delta}{s}\right] = \left[\frac{J}{s}\right] \tag{8}$$

Here, P is power and h_Δ has the numerical value of Planck's constant (6.626×10^{-34}) but with the units of [J/Δ] or energy per cycle. In short, the energy equation has been re-written in terms of power thus removing the necessity for the concepts of action and the photon. Written this way, it is clear to see that Planck's constant is the energy of one cycle or period of electromagnetic energy and can be considered as a quantum of energy. This equation (8) may be a more natural way of thinking about light since the power spectrum of light generally applies to the frequency domain. (The power spectrum of light is the distribution of the energies of a complex waveform among its different frequency components.) Here again, h_Δ, interprets as energy per cycle. This, I argue is the actual fundamental quantity of light. The photon, historically described as fundamental, is merely an arbitrary accumulation of light quanta, h_Δ, over an arbitrary 1-second time interval (i.e., photon energy is VARIABLE and therefore not fundamental).

We still need to reconcile how all oscillations (wavelengths) of light can embody the same energy, no matter what the frequency.

4. The Luminous Intensity of Light

In this section, it is argued that each cycle (wavelength) of light contains the same energy (no matter what frequency) and that it is the intensity of light that changes with wavelength. The units for intensity are as follows:

$$\left[\frac{J}{m^2\, s}\right] \tag{9}$$

From these units, it is clear to see that there are several ways to increase the intensity of a luminous signal. One way is to increase the energy [J] delivered to the same area in the same interval of time. There are two other ways to increase the intensity of the signal. One is to keep the energy constant but reduce the surface area with which the energy is being delivered and the other is to decrease the time interval with which the energy is being delivered. In a previous paper by the author, "Planck's Constant and the Law of Capacitance"[3], it was shown that both the area and the time interval decrease with a decrease in wavelength. A depiction of this is seen in Figure 1.

The top wave depicts a lower frequency (longer wavelength) signal. The bottom wave depicts a higher frequency (smaller wavelength) signal. To the right is the depiction of a detector of some kind. Each dot in this figure represents one quantum of energy. As you can see, for each frequency, each wavelength "contains" the same unit of energy. However, in the bottom signal, the 'same' energy is delivered to a smaller area of the detector in a shorter period of time. From this, it is clear to see how all wavelengths can carry the same energy and yet deliver different energy intensities to a detector (or solar panel). Longer wavelengths take longer to deliver the same energy to a larger area of the detector (i.e., intensity is lower). Also, from this schematic, it is clear so see that more energy **units** are delivered to the detector in unit time by the higher frequency signal than the lower frequency signal. This explains why higher frequency light "contains" more energy than lower frequency light.

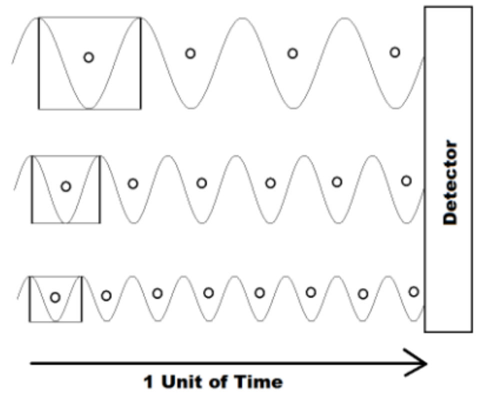

Figure 1. Three different wavelengths/frequencies of light.

5. Discussion 1

The purpose of the previous sections was to explore a previously discovered but not well known flaw in the unit section of of Planck's energy equation. According to the research of Dr. Juliana Mortenson, the problem stemmed from Planck's adoption of Wien's method for determining energy density which inadvertently removed the time parameter from his equations[1]. This explains why there is no time parameter in the equation $E = hf$. There also appears to be a flaw in the definition of frequency itself. 1960, the term "cycles per second" or [cps] was used for the unit of frequency. In 1960, the term was officially replaced by the Hertz with units of inverse time. Thus [1/s] replaced [cps] or cycles per second. In this definition, [1] appears to be the unit of the domain of cycles. The assumption here was that, since cycles are countable, the proper unit for the domain of cycles was the unit of countable numbers which is the numerical value of [1]. The flaw in this logic can be easily seen when one realizes that seconds are also countable (one steamboat, two steamboat etc, three steamboat, etc.). The same can be said of meters and kilograms. As well, as seconds, meters and kilograms are divisible, so too are cycles. If this weren't true, then we would not be able to reference a half cycle, a degree or a radian for that matter. Why should the domain of cycles be treated any differently than the domains of time, space, mass and charge? In Modified Unit Analysis, the Domain of Cycles was explicitly introduced as its own domain, separate from the domains of time, space, mass and charge, and the label, [1], is replaced by the label, [Δ], as the unit of this domain.

Another flaw comes from the fact that 1 is also the unit of the real numbers. The numerical value of [1] in the unit section has different meaning than the numerical value of 1 in the body of the equation. It cannot be used in the same manner. For example, E x 1 = E but the units [J x 1] does not evaluate to [J] since the [1] in the unit section corresponds to 1-cycle, not the real number 1. Technically, [J x 1] evaluates to [J x 1-cycle] = [J Δ] which is technically not equal to [J].

Finally, looking at equation 3, it is obvious that the [s] from the historical action constant is meant to cancel with the [s] from the frequency term, just as it is obvious that the two [Δ] units should cancel. Historically, the [s] from the action constant was allowed to cancel with one of the [s] terms from the units of [J] leaving h with the units of angular momentum:

$$E = hf \left[kg \frac{m}{s} \frac{m}{\cancel{s}} \cancel{s} \frac{1}{s} = \frac{kg\, m^2}{s} \frac{1}{s} \right] \tag{10}$$

In MUA, this is not recommended since the [s] from the action constant is meant to pair with the [s] from the frequency term. Although it may appear now that the frequency term is unit-less, it is in fact not unit-less. Even though it looks like they should cancel, for completeness, they still need to be written. In MUA, cancellation of units is highly discouraged as it destroys information. As such, in MUA, the units $[s/\Delta \times \Delta/s]$ need not cancel.

The historical interpretation of Planck's energy equation has lead to some strange concepts such as the uncertainty principle, the action constant, the photon and the quantization of angular momentum. MUA offers a more complete notation of unit analysis that, when applied to Planck's energy equation, leads to a different interpretation of light as you will see. All equations that contain Planck's constant, h or $\hbar$ need to be reexamined from the perspective of MUA. In the next section, MUA is applied to the Heisenberg Uncertainty Principle leading to a surprisingly certain conclusion.

6. The Heisenberg Uncertainty Principle

The Heisenberg uncertainty principle asserts that there is a fundamental limit to the precision with which certain pairs of physical properties of a particle can be known. The two relations in question are as follows:

$$\Delta x \, \Delta p \geq h \tag{11}$$

$$\Delta E \, \Delta t \geq h \tag{12}$$

The standard interpretation of the first relation is that the position and momentum of a particle cannot be simultaneously measured with arbitrary high precision. There is a similar interpretation for the product of the uncertainties of energy and time as seen in the second relation. In equation (4) of this article, the time parameter from the unit section was decoupled from the unit of Planck's constant and a measure-time variable, t_m, was added to the body of the equation. Using the logic of this equation (4) a similar approach is taken with the two above relations. Let's do the second one first:

$$\Delta E \, \Delta t \geq h_\Delta \, \Delta t \tag{13}$$

Here, $\Delta t = t_m$ and interprets as time interval. The Δt's cancel on each side and you end up with the following relation:

$$\Delta E \geq h_\Delta \tag{14}$$

The interpretation of this relation is quite simple. The smallest change in energy that can possibly be detected and measured is the quantum of energy or h_Δ = 6.626×10^{-34} Joules. Next we will address the position-momentum relation in (11). Again, using the logic from equation (4), the position-momentum relation is written as:

$$\Delta x \, \Delta p \geq h_\Delta \, \Delta t \tag{15}$$

Dividing both sides by Δt gives the following:

$$\frac{\Delta x \, \Delta p}{\Delta t} \geq h_\Delta \tag{16}$$

The units of distance, Δx, are [m], Δp has the units of momentum, [kg m/s], and the units of time, Δt are [s]. Thus, the units of the left side of this relation are [kg m/s m/s] or the units of energy. This reduces to the previous relation:

$$\Delta E \geq h_\Delta \tag{17}$$

In short, by decoupling the extra [s] unit from Planck's constant, as was done in equation (4), a clear, understandable and very certain relationship presents itself. There is nothing special nor is there anything uncertain about this relationship as it tells clearly that one cannot measure a change in energy smaller than 6.626×10^{-34} Joules. If this is true, then there must be a smallest detectable, measurable temperature as well.

7. Boltzmann's Constant and Temperature

If the minimal detectable energy is the quantum of energy or h_Δ, then this must correspond to a minimum detectable temperature. The units for Boltzmann's constant are:

$$K_b \left[\frac{J}{K} \right] \tag{18}$$

In order to convert energy to temperature, one must divide energy, E, by Boltzmann's constant:

$$T = \frac{E}{K_b} \tag{19}$$

When we apply the quantum of energy, h_Δ, to this equation, we get a value of $4.799243 \times 10^{-11} K$. According to relation (14), there exists a quantum of energy below which no energy can be detected. In other words, no temperature below $4.799243 \times 10^{-11} K$ can ever be created nor detected. The coldest temperature ever "created" was by a group at MIT who created and measured a temperature of around 500 picokelvin [4] or $5 \times 10^{-10} K$, just one order of magnitude higher than the lowest temperature possible, if in fact h_Δ is the smallest detectable energy.

In the previous sections, MUA is used to fix the flaw in the units of the "photon" energy equation and remove the uncertainty of the uncertainty principle. The photon energy equation was re-written in terms of power thus removing the concept of action altogether. Most importantly, the units for luminosity were used to show "how" all wavelengths of light can contain the same energy unit, h_Δ, no matter what the frequency, contrary to standard thinking. Using Modified Unit Analysis, as summarized below, the true nature of light can finally be revealed.

8. Summary of Modified Unit Analysis

Using the logic outlined in the previous sections, Modified Unit Analysis, MUA, is specified as follows:

1. The Domain of Cycles, separate from the domains of time, space, mass and charge, is added to unit analysis.
2. The unit of the Domain of Cycles has the label [Δ]. This applies to both cyclic frequency and flow frequency and generalizes to the unit of smallest change.
3. The unit Δ must be explicitly written in the unit section.
4. The unit of frequency, f, is [Δ/s].
5. The unit of period, T, [s/Δ].
6. The unit of wavelength, λ, is [m/Δ].
7. The unit of wavenumber, k, is [Δ/m],

9. The Electronic Nature of Light

There is another power equation that is very similar to equation (8):

$$P = V\,I\;[\frac{J}{C}\,\frac{C}{s}] = [\frac{J}{s}] \tag{20}$$

This is the equation for power in an electronic circuit. Here, Voltage, V, has units [J/C] and current, I, has units [C/s]. Notice how the units for this equation look very similar to the units for equation (8) only the unit "cycle" [Δ] is replaced by the unit "coulomb" [C]. An analogy between these two equations will now be discussed.

One coulomb is defined as the charge transported (in a circuit) by a current of 1 ampere during a 1 second time interval. In other words, the coulomb is defined in terms of flow rate or frequency. As light propagates through space, charge propagates through a circuit. The rate with which wavefronts of light pass by a point in space determines the electromagnetic frequency. The rate with which charge passes by a point in the circuit determines the flow frequency of the current. In this manner, frequency of light and current flow rate within a circuit are conceptually analogous (self-similar). In these two equations (8 and 20), cycle is analogous to Coulomb, h_Δ is analogous to voltage (V) and frequency, f, is analogous to current (I). The implication here is that light "flowing" through the medium of space can be modelled in terms of current flowing through a circuit of some kind.

In a previous paper by the author, "Planck's Constant and the Law of Capacitance"[3], the exact value of h is derived from first principles using the law of capacitance. It is well known that an oscillating circuit can be built using capacitors and inductors. Since electromagnetic radiation is an oscillating phenomenon, then it could be modelled using capacitors and inductors as follows:

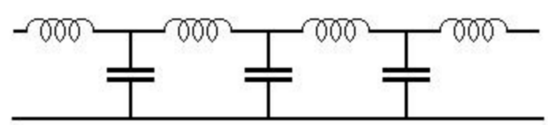

Figure 2. Electromagnetic wave as an electronic circuit.

The capacitors in parallel ensure that the voltage remains constant. The inductors in series ensure that the current remains constant. The arrangement of this circuit would ensure constant power during propagation (transmission). This is in fact a schematic diagram of a powerline circuit. The similarities between equation (8) and equation (20) suggests an isomorphism between electromagnetic "waves" and current flowing through a circuit.

Although this section may seem out of context with the subject matter of this article, its main purpose was to show the similarity between the power equation for an electronic circuit, equation (20), and the power equation derived earlier, equation (8), and to give a context with which the electromagnetic nature of light can be visualized.

10. The Wave Ψ Nature of Light

Technically, in wave theory, all waves are continuously *sloshing* between potential energy and kinetic energy. In fact, this is true of all oscillators, from pendulums to springs to water waves to sound waves. This is also true in the electronic oscillator made up of capacitors and inductors. As capacitors store potential energy, inductors store kinetic energy. In an oscillating circuit, voltage (potential) and current (kinetic) are 90 degrees out of phase with each other, that is, when the current through the inductor is maximal, the voltage over the capacitor is minimal, and vice versa. Sine waves and cosine waves are also 90 degrees out of phase with each other which is why these mathematical entities are used to model electronic circuits. If electromagnetic wave propagation is analogous to (isomorphic to) the propagation of power through power lines, as depicted in Figure 2, then it makes logical sense to model electromagnetic waves using sine and cosine waves as follows:

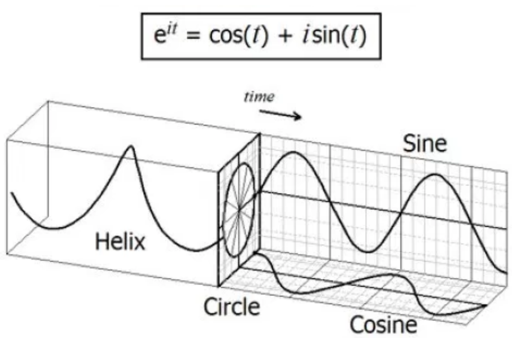

Figure 3. Euler's formula and depiction of the wavefunction.

Historically, and by convention using Maxwell's equations, electromagnetic wave propagation is modelled using two cosine waves (via the plane wave derivation) such that the electro (potential) component and magneto (kinetic) components are in phase with each other as depicted in the following diagram:

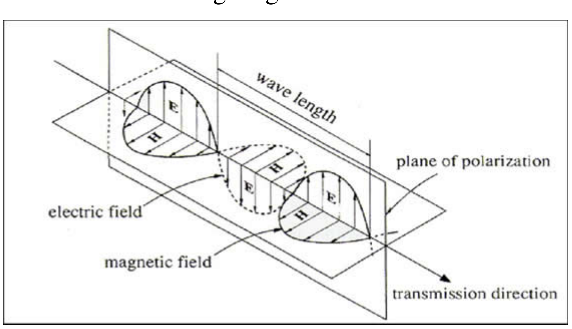

Figure 4. Maxwell's Plane Wave

This is the standard diagram used throughout the physics community to depict the propagation of light through the vacuum of space. However, in ALL other oscillators and wave phenomenon propagating in a medium, the kinetic component and potential components are 90 degrees out of phase as shown in Figure 3. Why should light waves behave so much differently than all other oscillating wave phenomenon? Short answer; they don't. Figure 3 is the correct mathematical model for light propagation and Figure 4 is just "plane" wrong. So, what happened? It turns out that Maxwell et al may have made a mistake too. See Appendix B.

11. Maxwell's Plane Wave Equation

In this section, we demonstrate how MUA affects the interpretation of the plane wave equation, given as follows:

$$\frac{\partial E_y}{\partial z^2} = \varepsilon\mu\frac{\partial^2 E_y}{\partial t^2} \tag{21}$$

Here:

$$E_y = A_1 cos(wt - kz) + A_2 cos(wt + kz) \tag{22}$$

and:

$$k = \frac{w}{c} \tag{23}$$

The symbols ε and μ correspond to the permittivity and permeability of the medium and k is the wavenumber with units [1/m]. Applying standard unit analysis to the term (wt - kz) gives as follows:

$$(wt - kz)\ [\frac{1}{s}s - \frac{1}{m}m] = [1 - 1] \tag{24}$$

In other words, this expression is unitless. Clearly, one can see how the numerical value of [1] in the unit section of an equation can lead to ambiguity. In MUA, the units are written as follows:

$$(wt - kz)\ \left[\frac{\Delta}{s}s - \frac{\Delta}{m}m\right] \tag{25}$$

Here, the [1] is replaced by the unit of the domain of cycles, [Δ]. As stated earlier, canceling terms in Modified Unit Analysis is highly discouraged as it destroys information. For example, in (25), if we cancel the [s] and the [m] terms, we would end up with $[\Delta - \Delta]$ which is still ambiguous as it give the false impression that these two terms can operate on each other and give a meaningful result. Looking more closely, you will notice that the term on the left has frequency in the Domain of Time and the term on the right has frequency in the Domain of Space. To distinguish these two Δ terms, a subscript is added as follows:

$$(wt - kz)\ \left[\frac{\Delta_s}{s}s - \frac{\Delta_m}{m}m\right] = [\Delta_s - \Delta_m] \tag{26}$$

Now, we can cancel the [s] and [m] terms in the unit section as the information about what domain the Δ term belongs to is now recovered. Here's the problem. The Δ_s term on the left and the Δ_m term on the right belong to different domains, the Domain of Time and the Domain of Space respectively. These two domains cannot operate on each other directly. They can only be compared through a ratio: [m/s] for example. The domains of time and space are not orthogonal and so they do not form a vector space. In other words, the two terms, *wt* and *kx*, cannot be added (nor can they be subtracted). How does one add things that have no common basis. Aside from the fact that they both contain frequency terms (in different domains), wt and kz have absolutely no basis with which to be compared (i.e., they have nothing in common).

In MUA, frequency terms in the Domain so Space cannot be added to (or subtracted from) frequency terms in the Domain of Time, and vice versa, thus, the expression (wt - kz) makes no logical or mathematical sense. Therefore, any mathematical derivation that uses this expression, including Schroedinger's equation, is erroneous (i.e., inherently flawed).

12. Discussion 2

Paul Dirac was once asked, "How do you find new laws of physics" and he replied, "I play with equations." The author herein, "plays" with unit analysis. Unit analysis is about interpretation and playing with unit analysis, via Modified Unit Analysis, has led to some interesting interpretations that differ from standard thinking. The interpretations of the past has led to some strange concepts such as the uncertainty principle, the quantum of action and the photon. What if this was all because we got unit analysis wrong when we were first developing quantum mechanics? What if all the strangeness goes away if we just make this small change, Δ, to the language of unit analysis? What if the correct model for light is the same as the model for all other oscillating (wave) phenomenon? This would certainly simplify a lot of things.

13. Conclusion

It is the contention of the author that a mistake was made by convention more than 100 years ago when the units of frequency were given as [1/s] (since the [1] in the unit section is ambiguous). In Modified Unit Analysis (MUA), the Domain of Cycles is added as a domain of the system, separate from the domains of time, space, mass and charge. The unit of cycle is assigned a unique label, Δ. The units of frequency in the domain of time are written as $[\Delta/s]$; the units of frequency in the domain of space (the wavenumber) are written as $[\Delta/m]$; the units of wavelength are written as $[m/\Delta]$; the units of period are written as $[s/\Delta]$. If both temporal and spatial frequency terms appear in the same expression, a subscript is added to the delta term, Δ_s and Δ_m to disambiguate the delta terms. This provides a more complete and balanced unit analysis when used correctly. In particular, it leads to a different, and hopefully, more understandable concept of light as a wave, just like any other "wave" propagating through a medium.

13.1. Appendix A: The Momentum Equation

In this section, a new constant of nature, quantum of momentum, is derived. This is not new, and has been done before [7], but the logic outlined herein uses the language and notation of MUA. Traditionally the relationship between Planck's constant and momentum is written as follows:

$$p = \frac{h}{\lambda} \tag{27}$$

Using the logic of equation (4), the following is written:

$$p = \frac{h_\Delta \Delta t}{\lambda} \tag{28}$$

Dividing both sides by Δt gives the following force equation:

$$\frac{p}{\Delta t} = \frac{h_\Delta}{\lambda} \tag{29}$$

This equation has the units of force. Looking at this equation, it is clear to see that force increases with shorter wavelength (higher frequency) light as expected. Using the relationship between wavelength and frequency, $\lambda = c/f$ the following is written:

$$\frac{p}{\Delta t} = \frac{h_\Delta}{c} f \tag{30}$$

Since both h_Δ and c are constants, a new quantum constant, corresponding to the quantum of momentum, p_q, can be written:

$$\frac{h_\Delta}{c} = p_q = 2.2102189 \times 10^{-42}\ [\frac{kg\ m}{s}] = [P] \tag{31}$$

Interestingly, this exact value appears in the NIST standard[5] but with units [kg] and is referred to as the "inverse meter-kilogram relationship". Even using the standard units of Planck's constant, [J s], the units of h/c do not evaluate to [kg] but instead, evaluates to [kg m]. In the NIST Reference on Constants, Units, and Uncertainty, the inverse meter-kilogram relationship is written,

$(1\,m^{-1})h/c$. Notice how they are mixing units with constants in this relationship? In MUA, this is strictly forbidden. The units for h/c are either [kg m] in standard unit analysis, or [kg m/s] in MUA. Using this new constant (of nature), the corresponding force equation in the frequency domain, can now be written as follows:

$$F = p_q\, f \quad \left[P\frac{s}{\Delta}\frac{\Delta}{s}\right] = \left[\frac{P}{s}\right] \tag{32}$$

Since there currently is no standard label for the unit for momentum, MUA uses [P] to represent the unit of momentum [kg m/s]. This equation (and associated units) looks similar to equation (8) but is a force equation instead of a power equation and the constant, p_q, interprets as the quantum of momentum. This new constant can be used in the following manner. Multiplying the quantum of momentum, p_q by the Compton frequency of the electron, $f_e = 1.2356 \times 10^{20}$ Hz, gives the following:

$$F_e = p_q \times f_e = 2.7309 \times 10^{-22}[\frac{P}{s}] \tag{33}$$

NIST refers to this exact value as the natural unit of momentum. The above equation, however, interprets as a force. A similar technique can be applied to the proton using the proton Compton frequency (f_p = c/protonComptonWavelength = 2.2687×10^{23} Hz) as follows,

$$F_p = p_q \times f_p = 5.01439 \times 10^{-19}[\frac{P}{s}] \tag{34}$$

As you can see, MUA opens up the door to a new constant of nature, quantum of momentum, which has physical meaning. Interestingly, the values f_e, f_p, p_q and F_e all appear in the NIST standard but, for some reason, F_p does not, even though equation (33) has similar interpretation to equation (34). Further investigation as to why is suggested.

13.2. Appendix B: Maxwell's Displacement Current

Maxwell's equations are generally thought to encoded everything we know about electricity and magnetism. That said, a group at IBM recently discovered a new, subtle, effect which they are calling the "camelback effect" that is not encoded into Maxwell's equations (A New Effect in Electromagnetism Discovered: 150 years later). In other words, Maxwell's equations are either incomplete or inherently flawed. Robert Distinti, an electrical engineer of 30+ years, has discovered a flaw in the at least one of Maxwell's equations. Distinti gets credit for discovering this problem that has illuded the physics community for the last 150 years. If Maxwell's equations are not just incomplete, but inherently flawed, then the derivation of the plane wave equation may also be flawed along with the plane wave model of light as depicted in Figure 4 of this article. The equation in question is as follows:

$$\nabla H = J + \frac{\partial D}{\partial t} \tag{35}$$

Thought experiment: A circular length of wire is imagined as a capacitor and the inductor in series. An imaginary barrier is place between the imaginary plates of the imaginary capacitor in the loop. The number of flux lines that cut the imaginary boundary is referred to as the displacement current. This is represented by the term on the right of the above equation, $\partial D/\partial t$. The flaw in the logic of this equation will now be outlined.

The divergence of the electric field lines gives you the charge density within a finite region:

$$p = \nabla \cdot D \tag{36}$$

Putting into point form gives:

$$p = \frac{\partial D_x}{\partial x} + \frac{\partial D_y}{\partial y} + \frac{\partial D_z}{\partial z} \tag{37}$$

For now, we will look at the x component only:

$$p = \frac{\partial D_x}{\partial x} \tag{38}$$

Multiply both sides by $\partial x/\partial t$:

$$p\left(\frac{\partial x}{\partial t}\right) = \frac{\partial D_x}{\partial x}\left(\frac{\partial x}{\partial t}\right) \tag{39}$$

The ∂D_x terms cancel and you end up with the time changing electric flux lines in the x direction:

$$p\left(\frac{\partial x}{\partial t}\right) = \frac{\partial D_x}{\partial t} \tag{40}$$

On the left, charge density times velocity is equal to current density leading to the following:

$$p\left(\frac{\partial x}{\partial t}\right) = J_x = \frac{\partial D_x}{\partial t} \tag{41}$$

Putting back into point form gives the following:

$$p\left(\frac{\partial}{\partial t}\right) = J = \frac{\partial D}{\partial t} \tag{42}$$

This result leads to the following conclusion:

$$\nabla H = J + \frac{\partial D}{\partial t} = 2 \times J \tag{43}$$

This herein lies the problem. How can this possibly be true? If this were true, then why didn't Maxwell write $\nabla H = 2J$? According the the logic presented in this section, the following appears to be true:

$$\nabla H = J = \frac{\partial D}{\partial t} \quad (44)$$

In other words, displacement current and current density are one in the same. If equation (35) is wrong, then this calls into question Maxwell's plane wave derivation along with the plane wave interpretation of light as depicted in Figure 4. Further investigation into this problem is highly recommended.

As a side note, it should be mentioned that Maxwell's equations are rarely used by electrical engineers. The standard wavefunction as depicted in Figure 3 is the equation that is used in practice. The Radar Handbook [6], for example barely mentions Maxwell's equations.

13.3. Acknowledgments

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