Chapter 1

Confined Light Has Inertia

At the end of this chapter there is Appendix A that gives a more rigorous mathematical analysis of the concepts first presented using only algebraic equations. It is therefore possible to read this chapter on two levels.

Light in a Reflecting Box: The concepts presented in this book started with a single insight. I realized that if it was possible to confine light in a hypothetical 100% reflecting box, the confined light would exhibit many of the properties of a fundamental particle. In particular, a confined photon would possess the same inertia (rest mass) and same weight as a particle with equal internal energy ($E = mc^2$). If the box is moving, a confined photon also exhibits the same kinetic energy, same de Broglie waves, same relativistic length contraction and same time dilation as an equal energy particle.

It is an axiom of physics that a photon is a massless particle. Massless particles do not have a rest frame of reference. They are moving at the speed of light in any frame of reference. However, if light is confined in a box, it is forced to have a specific frame of reference. This "confined light" then exhibits properties normally associated with a rest mass of equivalent energy ($m = E/c^2$) in the frame of reference of the box. This will first be analyzed using the following special relativity equation:

$m^2 = \left(\frac{E}{c^2}\right)^2 - \left(\frac{p}{c}\right)^2$ where: p is momentum and E is energy (equation 1)

Note to the reader: The first time symbols are used, they will be identified in the text. All the symbols used in the book and the important equations are also available in Chapter 15. It is recommended that you take a moment and look at chapter 15. If you are reading this book online, it is recommended that you print out Chapter 15 (10 pages) as an essential quick reference.

If a "particle" has energy of $E = pc$, then substituting this into the above equation gives:

$$m^2 = \left(\frac{p^2c^2}{c^4}\right) - \left(\frac{p^2}{c^2}\right) = 0$$

In other words, when $E = pc$, then a "particle" has no rest mass. Now, momentum is a vector, so a very interesting thing happens when we apply equation #1 to confined light. For example, a single photon confined between two reflectors is a wave traveling both directions simultaneously. The total momentum of this photon is zero because the two opposite momentum vectors nullify each other. Substituting $p = 0$ into the equation #1 yields: ($m = E/c^2$). In other words, confined light satisfies the definition of rest mass.

Another example of a photon gaining rest mass is a photon propagating through glass. If the glass has an index of refraction of 1.5, then the photon propagates at only 2/3 the speed of light in a vacuum and the momentum of the photon is reduced. The photon does not change energy when it enters the glass, but some of its momentum is imparted to the glass upon entrance and this momentum is returned to the photon upon exit. While the photon is propagating in the glass, it can be thought of as possessing some rest mass because $E \neq pc$. In other words, glass that has light propagating through it has more total mass (more inertia) than the same glass without any light propagation. It is also possible to analyze this more deeply and get into forward scatter and phase shifts introduced by the atoms of the glass. This analysis implies that the light has undergone partial confinement as it propagates through the glass at less than the speed of light in a vacuum. This partial confinement adds a small amount of "rest mass" to the glass.

The following example gives a deeper physical insight into how it is possible for confined light to exhibit mass. Suppose that a laser cavity has a 1 meter separation between two highly reflective mirrors. This is a 2 m (6.67 ns) round trip for light reflecting within this cavity. Light exerts photon pressure on absorbing or reflecting surfaces. The force exerted on an absorbing surface is $F = P/c$ or twice this force is exerted on a reflecting surface $F = 2P/c$ where $F =$ force and $P =$ power. If the laser in this example had 1.5×10^8 watts circulating between the two mirrors (reflecting surfaces), the energy confined between the two mirrors would be equal to 1 Joule and a force exerted by the light on each mirror would be one Newton in an inertial frame of reference.

Suppose that the laser is accelerated in a direction parallel to the optical axis of the laser. In the accelerating frame of reference, there would be a slight difference in the frequency of the light striking the two mirrors because of the mirror acceleration that occurs during the time required for the light to travel the distance between the two mirrors. The front mirror in the acceleration direction would be reflecting light that has Doppler shifted to a lower frequency compared to the light that is striking the rear mirror. If we return to the example of 1.5×10^8 watts of light circulating between two mirrors separated by one meter, then the force exerted against the front mirror would be slightly less than one Newton and the force exerted against the rear mirror would be slightly more than one Newton because of the difference in Doppler shifts. This force difference can be interpreted as the force exerted by the inertia of 1 Joule of confined light. The inertia of 1 Joule of confined light exactly equals the inertia of a mass with 1 Joule of internal energy (1.11×10^{-17} kg). For comparison, this mass is equal to about 6.6 billion hydrogen atoms.

While general relativity treats energy in any form the same, particle physics does not. The Standard Model of particle physics suggests that leptons and quarks require the hypothetical Higgs field to create the inertia of these particles. Therefore, in this example 6.6 billion hydrogen atoms require a Higgs field for inertia but an equal energy of confined light exhibits equal inertia without the need of a Higgs field. In fact, the inertia exhibited by the confined light is ultimately traceable to the constancy of the speed of light.

If we place the laser with 1 Joule of confined light stationary in a gravitational field, the confined light will exert a net force on the two mirrors equivalent to the weight expected from 6.6 billion hydrogen atoms. If the laser is oriented with its optical axis vertical, then the net force difference comes from what is commonly called the gravitational red/blue shift. This name is a misinterpretation that will be discussed later. The point is that more force is exerted on the lower mirror than the upper mirror because of the gravitational gradient between these two mirrors. If the laser is oriented horizontally, there will be gravitational bending of the light. The mirror curvature normally incorporated into laser mirrors easily accommodates this slight misalignment. However, the bending of light introduces a downward vector component into the force being exerted against both mirrors. This vector component is the weight of the light. It is true that general relativity teaches that energy in any form exhibits the same gravity. Therefore the gravitational similarity is expected. However, this does not automatically translate into giving inertia to quarks and leptons. The concept that confined light has weight and inertia has been explained differently in the article "Light Is Heavy"[1]

Confined light also exhibits kinetic energy when it is confined in a moving frame of reference. Suppose that the laser with 1 Joule of confined light travels at a constant velocity relative to a "stationary" observer. Also suppose that the observer sees the motion as traveling with the optic axis of the laser parallel to the direction of motion. The stationary observer will perceive that light propagation in the direction of motion is shifted up in frequency and light propagating in the opposite direction is shifted down in frequency. Combining these perceived changes in frequency result in a net increase in the total energy of the confined light. (Appendix A) This energy increase is equal to the kinetic energy which would be expected from the relative motion of a mass of equal internal energy. Appendix A also shows that the energy increase (kinetic energy) is correct even for relativistic velocities. The kinetic energy of the confined light is ultimately traceable to the constancy of the speed of light.

Confined Black Body Radiation: Thus far, the example of confined light has used a laser with highly reflecting mirrors. An alternative example could use an ordinary cardboard box at a temperature of 300°K with an internal volume of 1 m^3. The blackbody radiation within this box would have infrared light being emitted and reabsorbed by the internal walls. For the stated conditions, the blackbody radiation within the box would be about 6.1×10^{-6} J of

[1] http://www.tardyon.de/mirror/hooft/hooft.htm

radiation in flight within the volume of the box at any instant. This energy is equivalent to the annihilation energy of about 40,000 hydrogen atoms. Even though the black body radiation example is slightly harder to see, the result is similar to having reflecting walls. The confined black body radiation exhibits inertia, weight and relative motion exhibits kinetic energy. Carrying this blackbody radiation example further, let's consider the sun with a core temperature of about 15,000,000°K. At this temperature, the radiation is primarily at x-ray wavelengths. This confined x-ray radiation has inertia equivalent to about a gram per cubic meter. At a higher temperature where a star can burn carbon, the inertia of the confined x-rays is equivalent to the inertia of an equal volume of water (density = 1000 kg/m^3). Once again, no Higgs field is required for confined radiation to exhibit inertia.

The examples used above had bidirectional light traveling in a laser or multi directional light traveling within a black body cavity. It would also be possible to confine light by having the light traveling in a single direction around a closed loop. For example, light could be confined by traveling around a loop made of a traveling wave tube or fiber optics. Also, it is not necessary to limit the discussion to light. Gravitational waves are also massless because they propagate energy at the speed of light. There are no known reflectors for gravitational waves, but it is hypothetically possible to imagine confined gravitational waves. If there were confined gravitational waves, they would also exhibit the rest mass property of inertia and exhibit kinetic energy when the confining volume exhibits relative motion.

A photon is often described as a "massless particle". We now see that a qualification should be added because only a freely propagating photon is massless. A confined photon possesses rest mass (possesses inertia). Both photons and gravitational waves are examples of energy propagating at the speed of light. In chapter 4 another form of energy propagating at the speed of light will be introduced (waves in spacetime). This also exhibits inertia when confined. From these considerations, the following statement can be made:

Energy propagating at the speed of light exhibits rest mass (inertia) when it is confined to a specific frame of reference.

Constraint on Higgs Mechanism: Imagine what it would be like if confined light (or confined gravitational waves) exhibited a different amount of inertia than a particle of equal energy. For example, suppose an electron and positron are confined in the 100% reflecting box. After some time the electron and positron interact to form two gamma ray photons of equal energy. Would the total inertia of the box be any different when it contained the electron and positron compared to containing confined photons of equal energy? If there was any difference, (even at relativistic velocity), then this would be a violation of the conservation of momentum. The equal energy confined photons must have **exactly** the same inertia as the confined particles under all conditions.

The standard model of particle physics explains the inertia of a fundamental particle (a fermion) results from an interaction with the hypothetical Higgs field. This explanation says that a muon interacts more strongly than an electron, therefore a muon has more inertia. However, the inertia imparted by the Higgs field does not have a precise requirement for exactly how much inertia a muon or an electron should possess. Now we learn that the inertia of an electron with 511 KeV of internal energy must exactly match the inertia of 511 KeV of confined photons. Similarly, a muon with internal energy of 106 MeV must exactly match the inertia of 106 MeV of confined photons. Matching the inertia of a fundamental particle to the inertia of an equal amount of energy propagating at the speed of light but confined to a specific volume adds an additional constraint to any particle model. The particle model proposed later in this book perfectly matches the required inertia constraint. The Higgs mechanism does not currently satisfy this requirement.

de Broglie Waves: The similarity between confined light and particles does not end with the confined light possessing rest mass, weight and kinetic energy when there is relative motion. Next we will examine the similarity between the wave characteristics of confined light and the de Broglie wave patterns of fundamental particles. For example, particles with mass m and velocity v that pass through a double slit produce an interference pattern which can be interpreted as having a de Broglie wavelength λ_d given by the equation:

$\lambda_d = h/p$ where λ_d = de Broglie wavelength; h = Planck's constant; p = momentum

$\lambda_d = h/\gamma m_o v$ where $\gamma = \frac{1}{\sqrt{1-v^2/c^2}}$ m_o = particle's rest mass

$\nu_d = E/h$ where ν_d = de Broglie frequency E = total energy

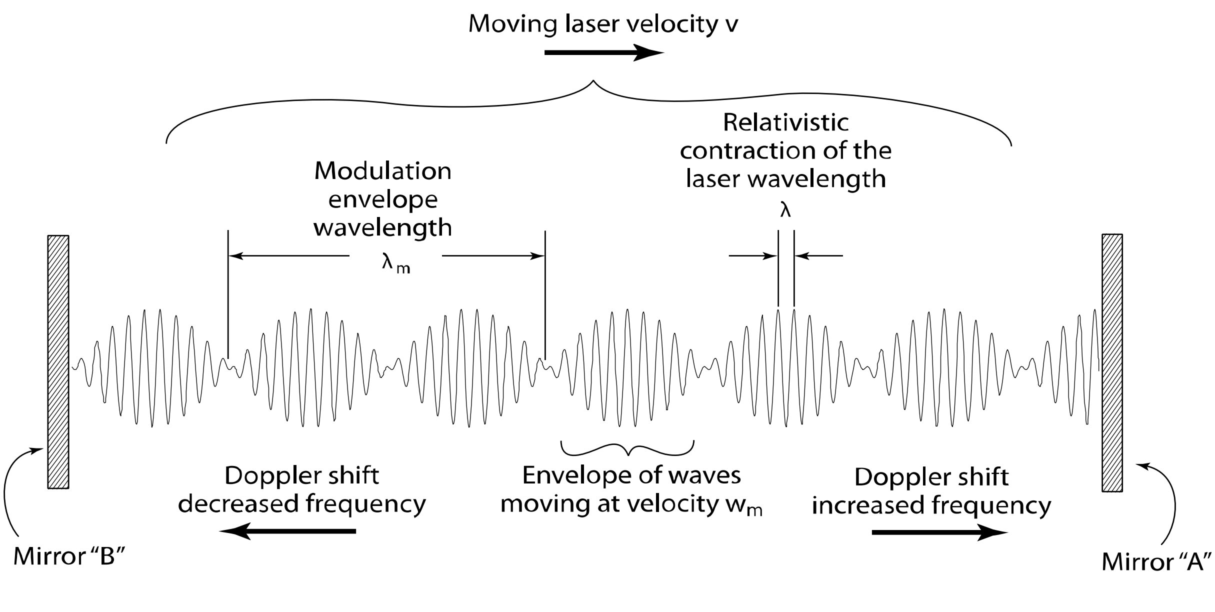

FIGURE 1-1 Wave pattern present in a moving laser due to Doppler shifts on the bi-directional light waves

The de Broglie waves have a phase velocity $w_d = c^2/v$ and a group velocity $u_d = v$. The phase velocity w_d is faster than the speed of light and the group velocity, u_d, equals the velocity of the particle, v.

There is a striking similarity between the de Broglie wave characteristics of a moving particle and the wave characteristics of confined light in a moving laser. Figure 1-1 shows a moving laser with mirrors A and B reflecting the light waves of a laser beam. Figure 1-1 is a composite because the light wave depicts electric field strength in the Y axis while the mirrors are shown in cross section. If the laser is stationary, the standing waves between the mirrors would have maximum electric field amplitude that is uniform at any instant. However, the laser in Figure 1-1 is moving in the direction of the arrow shown at velocity v. From the perspective of a "stationary" observer, light waves propagating in the direction of velocity v are Doppler shifted up in frequency, and light waves moving in the opposite direction are shifted down in frequency. When these electric field amplitudes are added, this produces the modulation envelope on the Doppler shifted bidirectional light in the laser as perceived by a stationary observer. This modulation envelope propagates in the direction of the translation direction but the modulation envelope has a velocity (w_m) which is faster than the speed of light ($w_m = c^2/v$) (calculated in appendix A). This is just an interference pattern and it can propagate faster than the speed of light without violating the special relativity prohibition against superluminal travel. No message can be sent faster than the speed of light on this interference pattern. The modulation envelope has a wavelength λ_m where:

$\lambda_m = \dfrac{\lambda_\gamma c}{v}$ λ_m = modulation envelope wavelength; λ_γ = wavelength of confined light

As seen in figure 1-1, one complete modulation envelope wavelength encompasses two nulls or two lobes. It will be shown later that there is a 180 degree phase shift at each null, so to return to the original phase requires two reversals (two lobes per wavelength).

The similarity to de Broglie waves can be seen if we equate the energy of a single photon of wavelength λ_γ to the energy of a particle of equivalent mass m. This will assume the non-relativistic approximation. Appendix A will address the more general relativistic case.

$E = \dfrac{hc}{\lambda_\gamma} = mc^2$ equating photon energy to mass energy therefore $m = \dfrac{h}{c\lambda_\gamma}$

$\lambda_d = \dfrac{h}{mv}$ λ_d = de Broglie wavelength;

$\lambda_d = \dfrac{\lambda_\gamma c}{v} = \lambda_m$ de Broglie wavelength λ_d = modulation envelope wavelength λ_m

The modulation envelope not only has the correct wavelength, it also has the correct phase velocity ($w_d = w_m = c^2/v$). The "standing" optical waves also have a group velocity of v. Therefore these waves move with the velocity of the mirrors and appear to be standing relative to the mirrors.

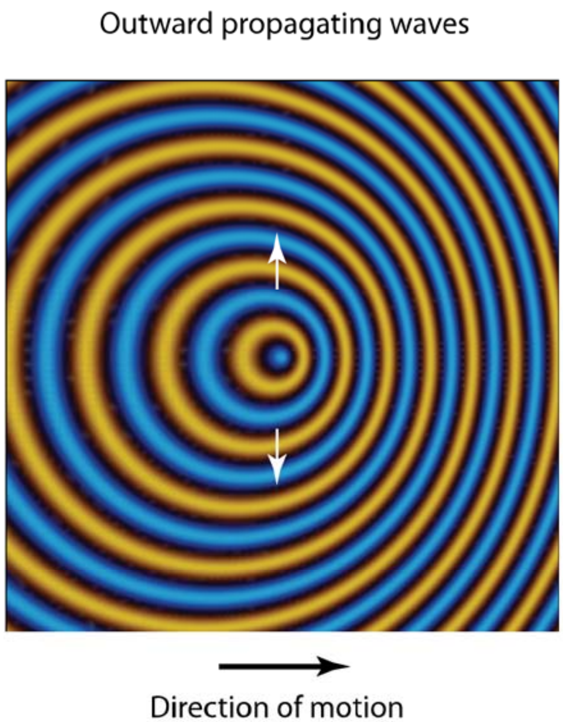

FIGURE 1-2 Doppler shift on outward propagating waves

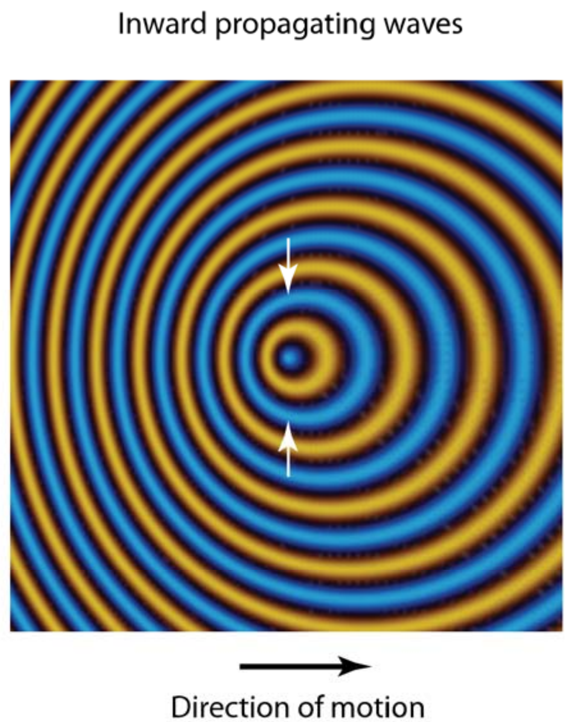

FIGURE 1-3 Doppler shift on inward propagating waves

de Broglie Waves in Radial Propagation: It is easy to see how the optical equivalent of de Broglie waves can form in the example above with propagation along the axis of translation. However, it is not as obvious what would happen if we translated the laser in a direction not aligned with the laser axis. We will take this to the limit and examine what happens when the waves propagate radially into a 360° plane that is parallel to the translation direction. To understand what happens, we will first look at figure 1-2 that shows the Doppler shifted wave pattern produced by waves propagating away from a point source in a moving frame of reference. The source is moving from left to right as indicated by the arrow. Waves moving in the direction of relative motion (to the right) are seen as shifted to a shorter wavelength and waves moving opposite to the direction of travel are shifted to a longer wavelength. Figure 1-3 is similar to figure 1-2 except that only waves propagating towards the source are shown.

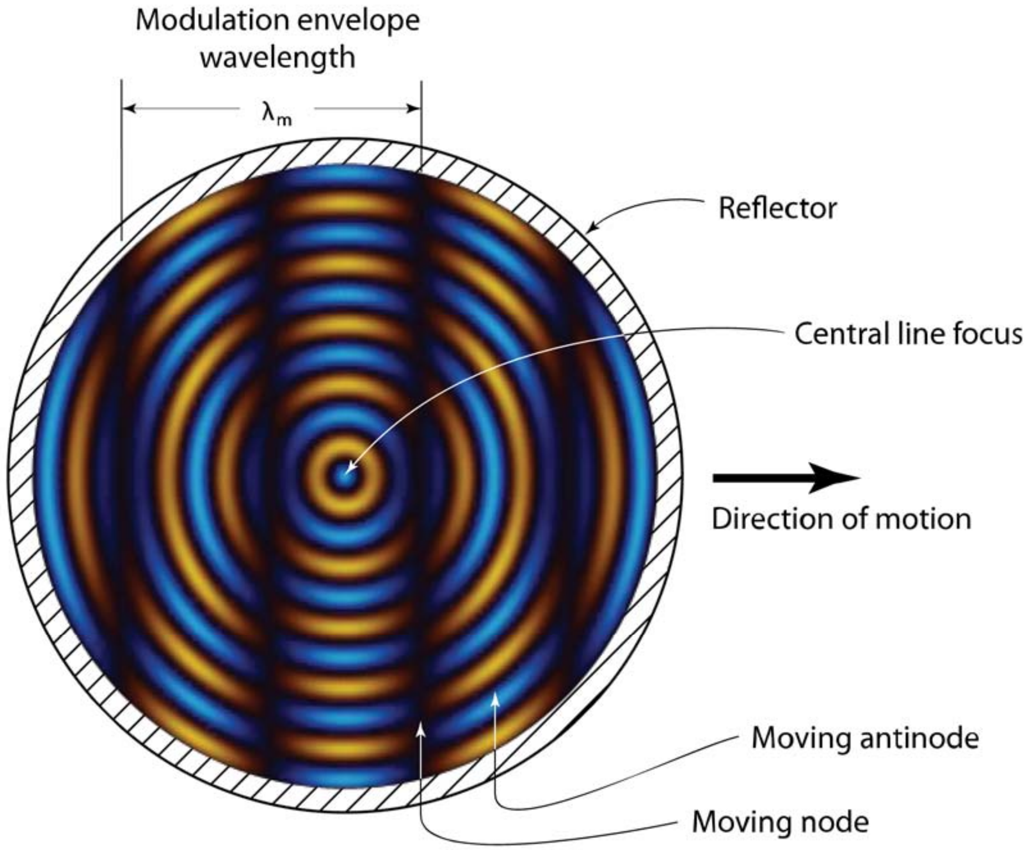

FIGURE 1-4 Wave pattern produced when radially propagating standing waves are observed in a moving frame of reference

Figure 1-4 shows what happens when we add together the outward and inward propagating waves shown in figures 1-2 and 1-3. Also a cross-sectioned cylindrical reflector has been added to figure 1-4. This reflector can be thought of as the reason that there are waves propagating towards the center. The central lobe of figure 1-4 can be thought of as a line focus that runs down the axis of the cylindrical reflector.

The vertical dark bands in figure 1-4 correspond to the null regions in the modulation envelope. These null regions can be seen in figure 1-1 as the periodic regions of minimum amplitude. There is a 180° phase shift at the nulls. This can be seen by following a particular fringe through the dark null region. If the wave is represented by a yellow color on one side of the null, this same wave is a blue color on the other side of the null. This color change indicates that a 180° phase shift occurs at the null. In figure 1-1, the reason that the wavelength of the modulation envelope λ_m is defined as including two lobes is because of this phase reversal that happens at every null. Therefore it takes two lobes to return to the original phase and form one complete wavelength.

The main purpose of this figure is to illustrate that de Broglie waves with a plane wavefront appear even in light that is propagating radially. This is a modulation envelope that is the equivalent of a plane wave moving in the same direction as the relative motion, but moving at a speed faster than the speed of light. Figure 1-4 represents an instant in a rapidly changing wave pattern.

There has also been an artistic license taken in this figure to help illustrate the point. Normally we would expect the electric field strength to be very large along the focal line at the center of the cylindrical reflector and decrease radially. However, accurately showing this radial amplitude variation would hide the wave pattern that is the purpose of this figure. Therefore the radial amplitude dependence has been eliminated to permit the other wave patterns to be shown. Another artistic license is the elimination of the Guoy effect at the line focus. The central lobe of a cylindrical focus should be enlarged by ¼ wavelength to accommodate the 90° phase shift produced when electromagnetic radiation passes through a line focus. Ultimately we will be transferring the concepts illustrated here to a different model that does not require this slight enlargement.

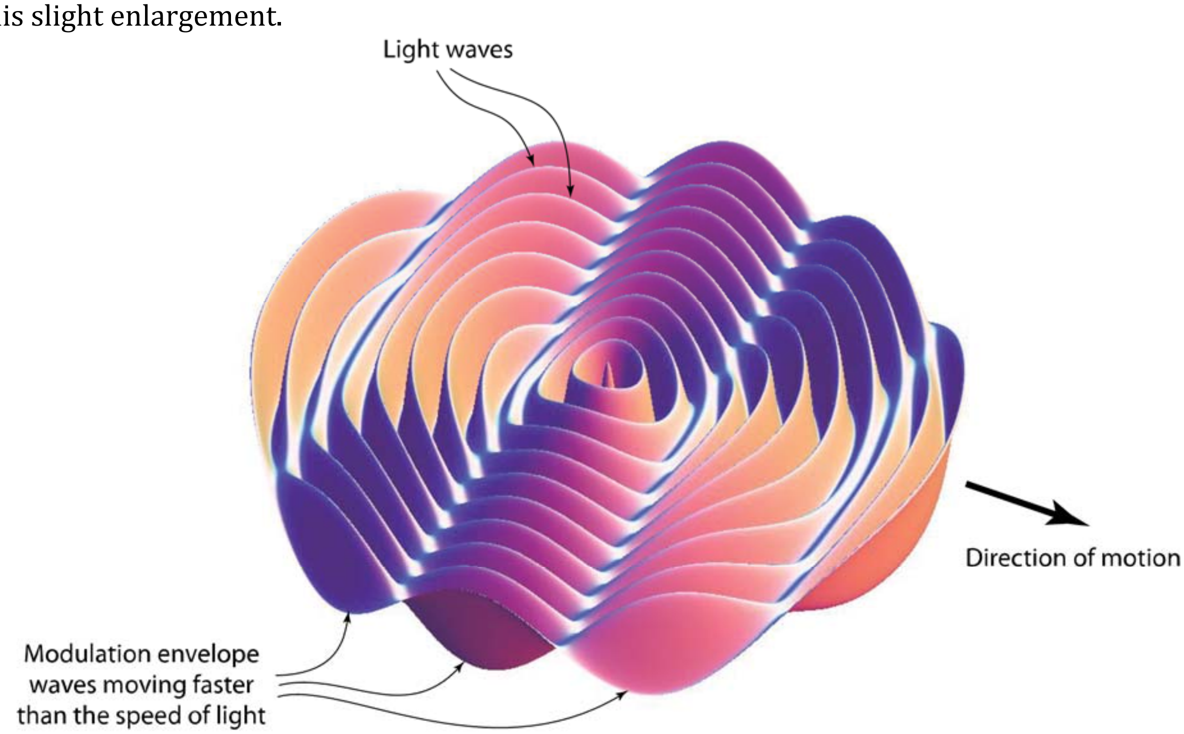

FIGURE 1-5 A three-dimensional representation of figure 1-4 where the Z axis is used to represent electric field

Figure 1-5 is a 3 dimensional representation of the wave pattern present in figure 1-4. In figure 1-5 the Z axis is used to represent the electric field. The cylindrical reflector has been removed from the illustration to permit the waves to be seen. Also as before, the radial amplitude dependence has been eliminated to permit the subtle modulation envelope to be seen. If figure 1-5 was set in motion, the concentric circular wave pattern would move as a unit. However, superimposed on this is the moving envelope of waves that are moving through this wave structure (waves on waves). This moving envelope of waves is moving faster than the speed of light in the same direction as overall motion ($w_m = c^2/v$).

The surprising part of figure 1-4 and 1-5 is that we obtain a linear modulation envelope imposed on the radial propagating waves. It does not make any difference what the propagation angle is, the equivalent of de Broglie waves are produced for all angles. The only requirement is that the wave has bidirectional propagation. If later we are successful in establishing a model of fundamental particles that exhibits bidirectional wave motion, that model will also exhibit de Broglie waves.

Next we are going to talk about relativistic length contraction. For illustration, we will return to figure 1-1. This figure shows the wave frozen in time and designates the distance that approximately corresponds to the laser wavelength λ. Actually, this distance only precisely equals the laser wavelength when there is no relative motion. In the example illustrated in figure 1-1, there is relative motion. The wave illustrated is the result of adding together a wave that has been Doppler shifted up in frequency to a wave that has been Doppler shifted down in frequency. The combination produces a peak to peak distance that is equal to the relativistic contraction of the laser wavelength.

This is reasonable when you consider that there are a fixed number of standing waves between the two mirrors. If the distance between the two mirrors undergoes a relativistic contraction, the standing waves must also exhibit the same contraction to retain the fixed number of standing waves. However, it is possible to reverse this reasoning. Rather than saying that the standing waves must contract to fit between the relativistic contracted mirror separation, it is possible to say that we might be getting a fundamental insight into the mechanics of how nature accomplishes relativistic contraction of physical objects. If all fundamental particles and forces of nature can ultimately be reduced to bidirectional waves in spacetime, then these bidirectional waves, will automatically exhibit relativistic contraction and the mechanism of relativistic contraction of even the nucleus of an atom would be conceptually understandable.

Similarly, the mechanism of relativistic time dilation would also become conceptually understandable. If we were to time the oscillation frequency of individual waves in the laser of figure 1-1, we would find that the oscillation frequency that results when we add these two Doppler shifted waves together slows exactly as we would expect for the relativistic time dilation of a moving object. Again this is traceable to the constant speed of light producing different Doppler shifts on the components of the bidirectional light. The sum of these two frequencies exhibits a net slowing that corresponds to relativistic time dilation.

Therefore the analysis in this chapter and appendix A shows that a confined photon in a moving frame of reference has the following 8 similarities to a fundamental particle with the same energy and same frame of reference:

1) The confined photon has the same inertia (rest mass): $m = \hbar\omega_c/c^2$
2) The confined photon has the same kinetic energy: $k_e = ½\, mv^2 = ½\, (\hbar\omega_o/c^2)\, v^2$
3) The confined photon has the same weight as the particle.
4) The confined photon (bidirectional propagation) has the same momentum.
5) The confined photon's envelope wavelength λ_s is the same as the particle's de Broglie wavelength: $\lambda_s = \lambda_d$
6) The confined photon's modulation envelope phase velocity is the same as the particle's de Broglie phase velocity: $v_s = w = c^2/v$
7) The photon's group velocity is the same as the particle's group velocity: $v_d = u$
8) The confined photon has the same relativistic length contraction: $\lambda_{dd} = \lambda_o/\gamma$

It is hard to avoid the thought that perhaps a particle is actually a wave with components exhibiting bidirectional propagation at the speed of light but somehow confined to a specific volume. This confinement produces standing waves that are simultaneously moving both towards and away from a central region.

Do we have any truly fundamental particles? If I defined a fundamental particle by the ancient Greek standard of indivisibility and incorruptibility, then there are none. An electron and a positron can be turned into two photons (and vice versa). An isolated neutron (2 down quarks and 1 up quark) will decay into a proton (2 up quarks and 1 down quark) plus an electron and an antineutrino. In fact, all 12 "fundamental" fermions of the standard model can be converted into other fermions and into photons. The simplest explanation for this easy conversion between "fundamental" particles is that there is a wave structure to these fermions. The truly fundamental building block of all fermions is the underlying wave in spacetime that allows these easy transformations. It is on the level of this truly fundamental building block that there is a similarity between confined light and particles. This thought process will be continued in chapter 4.

Note:
Chapters 2 and 3 lay groundwork that prepares the reader to understand the proposed model. Development of the spacetime based model of particles and forces starts in earnest in chapter 4.

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