# Chapter 11

## Photons

**Photons**: In chapter 9 we examined the simplified case of photons confined to a reflecting cavity. When we reduced the dimensions of the cavity to the minimum size that would support electromagnetic radiation of a particular wavelength, we called this condition "maximum confinement". Equations for the electric and magnetic field were developed for this maximum confinement condition. In this chapter we will develop a model of a freely propagating photon. This model will be incomplete, but hopefully this attempt at developing such a model will encourage others to improve on this model.

It is commonly argued that photons cannot just be waves because the photo-electric effect demonstrates that all the energy of a photon is transferred to a single electron in an absorbing atom. This concentration of energy can eject an electron from the surface of the photo-electric material. The reasoning is that if a photon was a wave, then the wave would distribute the photon's energy evenly over a surface and no single electron would receive the energy required to eject an electron from a surface. This reasoning assumes that the waves of a photon are similar to either a sound wave or perhaps a wave in the aether. A sound wave in air for example produces an oscillating displacement of many molecules. When a sound wave in air strikes a solid surface, it is really many individual molecules striking the surface independently. The energy of the sound wave is distributed over the surface. Similarly, if light is imagined as a wave in an omnipresent fluid called the aether, then waves in the aether would be evenly distributed over a surface and an electron would not be ejected from the surface.

**A photon possesses quantized angular momentum, not quantized energy. It is the quantized angular momentum that gives a photon its particle-like properties.**

Recall that a photon is an $\hbar$ unit of angular momentum propagating as a wave in the spacetime field. However, this wave is also quarantined in some way by the superfluid properties of the spacetime field. This results in a photon having quantized angular momentum. It is impossible to distribute quantized angular momentum to multiple locations. All the quantized angular momentum (and all the energy) is deposited as a single unit at a single location. This effect gives a photon particle-like properties when it interacts with matter. However, this does not require that a photon is an actual particle; it only requires quantization of angular momentum. Furthermore, the photo-electric effect is low energy Compton scattering. In chapter 10 it was shown that Compton scattering has a plausible wave explanation. Even though the photoelectric material has a surface work function, the basic Compton scatter wave interaction is the same. The quantized wave characteristics of the photon and the electron can eject the electron from the surface.

In Compton scattering the photon usually transfers some of its energy to the scattered electron (Fig. 10-12 shows the rare example of a photon transferring linear momentum but not energy). Even when a photon is reflected off a "moving" mirror, the reflected photon is Doppler shifted and therefore has different energy than it had before it reflected off the mirror. The point is that photons do not possess quantized energy. When a photon is emitted or absorbed, there is a transfer of $\hbar$ quantized angular momentum. Energy is also transferred, but the transfer of energy is just a byproduct of the transfer of quantized angular momentum.

This chapter will show a proposed model of a photon and explain how a photon can possess quantized angular momentum. Usually the angular momentum of a photon is an abstract concept that is dealt with mathematically. It is easy to write an equation that incorporates angular momentum but the hard part is to develop a physical model of a photon which incorporates angular momentum. Why is angular momentum quantized? What enforces this quantization of angular momentum? Answering these questions are another test of the proposed spacetime-based model of the universe.

**How Big Is a Photon?** The standard explanation for a photon's properties is to claim that a photon exhibits "wave-particle duality". Of course, this is not a conceptually understandable explanation; it is merely a name. In a double slit experiment, a photon seems to have the ability to pass through both slits simultaneously. This implies that a photon has a physical width. A photon also seems to have a physical length that is a function of the photon's spectral width. For example, a rubidium atom has a spectral line called the $D_1$ transition. When a rubidium atom goes through this transition, it emits a photon over about 26 ns. This implies that this photon is extends over a distance of about 8 meters. Furthermore, the spectral line width of this rubidium transition has a bandwidth that also implies a wave packet with this physical length using a Fourier transform. This is not just an 8 meter uncertainty in the location of the photon; it is an actual wave train that is 8 meters long at a wavelength of about 795 nm. The hyper fine transition of cesium 133 that is used in atomic clocks emits at a microwave frequency of about $9.2 \times 10^9$ Hz. This emission frequency is stable to better than one part in $10^{13}$. This extremely narrow bandwidth implies that the emitted photon is continuously emitted over about 1000 seconds and the length of the photon wave train is about $3 \times 10^{11}$ m. At the opposite extreme, the record for the shortest pulse of laser light (in terms of approaching the theoretical limit) is a mere 1.3 cycles per pulse. The current record for the shortest pulse of laser light is about $8 \times 10^{-17}$ seconds but that pulse contained several cycles and harmonics of a short wavelength.

The emission of a photon by an atom is often depicted as if it is an instantaneous event. However, this is known to be incorrect[1] because there is a time dependence of the wave function in a quantum transition. Experimental measurements have been made of samples undergoing spectroscopic transitions. These experiments confirm that there are no instantaneous quantum

[1] Macomber, J. D. *The Dynamics of Spectroscopic Transition;* John Wiley and Sons: New York, 1976.

jumps. Instead, the electric and magnetic properties undergo a smooth and continuous transition occurring over the emission time period which usually corresponds to the lifetime of the excited state.

There is a very good paper titled "How a Photon is Created or Absorbed"[2] that is also available online[3]. This online version has two good animations showing the oscillations of a hydrogen atom during the emission of a photon. This paper shows that there is an often ignored transition period required for the emission or absorption of energy in a transition between energy levels. There are numerous experimental observations that confirm that photons are emitted or absorbed over a time period corresponding to the inverse bandwidth. Quoting from the above article:

> The first experimental measurements of bulk samples undergoing spectroscopic transitions were obtained from nuclear magnetic resonance observations of the transition nutation effect[4] and spin echoes[5],[6] using coherent radiation produced by a single radio frequency oscillator. More recently, the analogous transition nutation effect[7],[8] and so called "photon echoes"[9],[10],[11] have been observed in molecular spectra using pulsed coherent laser radiation. These experiments confirm that there is no "quantum jumps" in the non-stationary state; rather there are smooth, continuous periodic changes in the magnetic and electrical properties of the system undergoing a transition.

An electron bound in an atom possesses less energy than an isolated electron. For example, 13.6 eV of energy is released when an isolated electron combines with a proton to form a hydrogen atom in the ground state. The binding energy can be considered to be a negative form of energy which means that binding releases energy and breaking a bond requires energy. The rotar model of fundamental particles says that an isolated electron is a rotating dipole in the spacetime field with a rotational frequency of about $1.24 \times 10^{20}$ Hz. When an electron and proton combine to form a hydrogen atom in the ground state, a photon is released with a frequency of about $3.3 \times 10^{15}$ Hz (~13.6 eV). According to the rotar model, the energy released when a hydrogen atom forms comes primarily from the electron losing energy and reducing its Compton frequency by about $3.3 \times 10^{15}$ Hz. The oscillations of the electron cloud shown in the above animation can be thought of as the interaction between the electron in two different energy

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[2] Henderson, G *J. Chem. Educ.* **1979**, *56*, 631-634
[3] http://www3.uji.es/~planelle/APUNTS/ESPECTROS/jce/JCEphoto.html
[4] Torrey, H. C. *Phys. Rev.* **76**, 1059 (1949).
[5] Hahn, E. L. *Phys. Rev.* **77**, 297 (l950).
[6] Hahn, E. L. *Phys. Rev.* **30**, 580 (l950).
[7] Tang, C. L.; Statz, H. *Appl. Phys. Lett.* **10**, 145 (1967).
[8] Hocker, G. B.; Tang, C. L. *Phys. Rev.* **184**, 356 (1969).
[9] Kurnit, N. A.; Abella, I. D.; Hartmann, S. R. *Phys. Rev. Lett.* **13**, 567 (1964).
[10] Abella, I. D.; Kurnit, N. A.; Hartmann, S. R. *Phys. Rev.* **141**, 391 (1966).
[11] Hartmann, S. A. *Sci. Amer.* **218**, 32 (1968).

states (two different frequencies) interfering with itself. These oscillations create waves in the spacetime field that remove this energy at the frequency of the oscillations. These waves are proposed to be the photon.

In chapter 9 it was shown that a photon was not an energy packet traveling THROUGH the spacetime field, but a wave traveling IN the medium of the spacetime field. Now we will develop the model of a photon further based on waves propagating within the vacuum fluctuations of the spacetime field. These waves will be shown to be distributed over a substantial volume of the spacetime field. Clearly such a structure cannot be visualized as a point particle. It only exhibits particle-like properties because it possesses quantized angular momentum combined with the property of unity. This combination gives waves in the spacetime field with quantized spin the ability to act as a unit and transfer their energy and quantized spin to a single rotar. The name "photon" is not really appropriate since the suffix "on" was coined specifically to imply particle properties. However, the name "photon" is flexible enough that it can adjust to a quantized wave explanation. Therefore no attempt will be made to replace the word "photon".

**Vacuum Energy Versus the Aether**: The aether was once believed to be an omnipresent fluid with a single frame of reference that served as the propagation medium for light waves. The concept of the aether implied that it should be possible to detect evidence of the earth's motion relative to the aether. For example, if this model of the aether was correct, there should be a detectable shift in interference fringes in the Michelson Morley experiment. This and numerous more recent experiments have confirmed that there is no evidence that any such relative motion exists. With this experimental evidence, the concept of the aether has been abandoned. This background makes the following seem like a radical proposal:

**A photon is a wave disturbance possessing quantized angular momentum that propagates in the medium of the vacuum fluctuations of the spacetime field.**

This concept was first introduced in chapter 9 but it is repeated here since any discussion of photons must be based on this concept. This sounds like I am merely substituting the term "vacuum fluctuations" for aether. However, there is a big difference. The properties of the vacuum fluctuations are such that it is impossible to detect any motion relative to these fluctuations (ignoring hypothetical experiments which probe the Planck frequency limits). Recall that vacuum energy (vacuum fluctuations) is a sea of dipole waves in the spacetime field that lack angular momentum. These waves are already propagating at the speed of light. Every part of a wave becomes the source of a new wavelet so the spacetime field becomes a sea of dipole wave distortions that are rearranging themselves at the speed of light. As previously explained, these chaotic waves that lack angular momentum make the quantum mechanical version of a vacuum. They are responsible for the appearance of virtual particle pairs, the uncertainty principle, the Casimir effect, the Lamb shift, etc.

Gravitational waves also propagate in the medium of the spacetime field. It is known that gravitational waves propagate at the speed of light in any frame of reference. If it was possible to do a Michelson-Morley experiment using gravitational waves, it would be impossible to detect motion relative to the medium of the spacetime field. Therefore the spacetime field possesses the ability to propagate waves at the speed of light as seen from any frame of reference.

It is also impossible to detect motion relative to the dipole waves that are an essential part of the spacetime field. Chapter 7 discussed the subject of spectral energy density in vacuum energy. That discussion is repeated here because it takes on new meaning when applied to detecting motion relative to vacuum energy.

> In quantum field theory, spacetime is visualized as consisting of fields. Every point in spacetime is treated like a quantized harmonic oscillator. The lowest quantum mechanical energy level of each oscillator is $E = ½\, \hbar\omega$. This concept leads to a spectral energy density $\rho(\omega)d\omega$ that is:
>
> $$\rho(\omega)d\omega = k\left(\frac{\hbar\omega^3}{c^3}\right)d\omega$$
>
> This spectrum with its $\omega^3$ dependence of spectral energy density is unique in as much as motion through this spectral distribution does not produce a detectable Doppler shift. It is a Lorentz invariant random field. Any particular spectral component undergoes a Doppler shift, but other components compensate so that all components taken together do not exhibit a Doppler shift. It should also be noted that neither cosmological expansion nor gravity alters this spectrum.[12]

Therefore, vacuum energy has completely different properties than the aether which is thought of as an omnipresent fluid which has a specific frame of reference. Normally we would say that it is impossible to detect motion relative to the vacuum energy. However, in chapter 14 we will examine the implications of the vacuum fluctuations having a maximum frequency equal to Planck frequency. Since it is impossible for the spacetime field to propagate a wave with a Doppler shifted frequency higher than Planck frequency or a wavelength shorter than Planck length, it is possible to imagine extreme frames of reference where the laws of physics are not covariant. However, since these are vastly outside of any experimental condition, this exception will be ignored until chapter 14.

[12] Puthoff, H.E. Phys. Rev. A Volume 40, p.4857, 1989 Errata in Phys. Rev A volume 44, p. 3385, 1991 See also New Scientist, volume 124, p.36, Dec. 2, 1989

The bosons such as photons have angular momentum of $\hbar$. These quantized angular momentum disturbances in the spacetime field, are not confined to a specific location like the rotar model. Instead the quantized angular momentum of a photon is distributed into an expanding wave that will be described in this chapter. When a photon is absorbed, the disturbance with quantized angular momentum would collapse and transfer all the quantized $\hbar$ angular momentum to the absorbing body (rotars).

**A Photon Is Not a Dipole Wave in the Spacetime Field**: A photon cannot be a quantized dipole wave in the spacetime field. A dipole wave creates an oscillating rate of time gradient. A rate of time gradient is capable of accelerating any matter, even a neutral particle such as a neutron. To prevent a violation of the conservation of momentum, dipole waves in the spacetime field are limited to a maximum displacement of spacetime of Planck length and Planck time as previously described. If a photon was a dipole wave, a focused laser beam would easily violate this restriction. Recall that rotars have this quantum mechanical limit of Planck length and Planck time. Therefore, the maximum energy density for a dipole wave in the spacetime field is equal to the energy density of the rotar volume of a rotar $(U_q)$. This knowledge can be converted to a maximum intensity ($\mathcal{I}$) for a dipole wave in the spacetime field with reduced wavelength $\lambda\!\!\!^{-}$ since $\mathcal{I} = Uc$ for radiation propagating at the speed of light. From previous calculations of rotars, we know that the energy density in the rotar volume of a rotar is: $U_q = \hbar c/\lambda\!\!\!^{-4}$. This energy density then sets an upper limit to the maximum intensity that could be achieved at the focus of a laser beam if photons were dipole waves in the spacetime field. Using $\mathcal{I} = Uc$, the maximum intensity of electromagnetic radiation that would violate the conservation of momentum if photons were dipole waves in the spacetime field is: $\mathcal{I}_{\max} = \hbar c^2/\lambda\!\!\!^{-4}$.

If photons were dipole waves in the spacetime field, then the maximum intensity allowable for a laser beam with a wavelength of about $10^{-6}$ m (reduced wavelength $\lambda\!\!\!^{-} \approx 1.6 \times 10^{-7}$ m) would be about $10^{10}$ w/m$^2$ ($10^4$ w/cm$^2$). Intensities in excess of $10^{20}$ w/cm$^2$ have been achieved at the focus of a pulsed laser at this approximate wavelength, so a photon is definitely not a propagating dipole wave in the spacetime field. A model will be developed that is a wave in the space dimensions of the spacetime field without affecting the rate of time. Gravitational waves can also have displacement amplitude that exceeds dynamic Planck length $L_p$ because they also do not cause a displacement of the rate of time. (They also are not dipole waves in the spacetime field.)

**Waves in Vacuum Energy**: So far we have talked about waves in the abstract. What are the waves of a photon made of? Photons are not propagating dipole waves in the spacetime field but the proposed answer is that they are a propagating polarization in the dipole waves that form the spacetime field (vacuum energy). In chapter 9 the proposal was made that an electric field is a polarized strain in the spacetime field. This produces the unsymmetrical effects associated with propagation of a neutral particle in the positive or negative electric field direction. This results in the one way time of flight distance between points being slightly different for opposite polarity directions. For example, if there is an electric field present, then the time required to go from point A to point B is longer than the time required to go from point B to point A. However, the round trip time is the same as expected from the speed of light and no electric field. This means that there is no change in proper volume and no change in the rate of time. A single photon with reduced wavelength $\lambda\!\!\!^-$ in maximum confinement had a difference in path length over a distance of $\lambda\!\!\!^-$ of $L_p$ and $n$ photons in maximum confinement produced a path length difference of: $\sqrt{n}L_p$. Since it is theoretically impossible to measure a distance accurate to Planck length, this explains why it is impossible to measure the wave properties of a single photon but it is possible to measure the wave properties of many photons (for example, the electric field of a radio wave).

The model of a single photon would be a wave possessing quantized angular momentum that propagates in vacuum energy. The dipole waves that form vacuum energy cannot possess angular momentum, so a disturbance carrying quantized angular momentum would be like a propagating phase transition that causes a small amount of dipole waves (the photon's energy and volume) to momentarily lose its superfluid properties. Such a wave would momentarily be giving a distributed angular momentum to vacuum energy. Apparently this disturbance is a transverse wave that possesses the polarization characteristics we normally associate with a photon. Such a wave in vacuum energy would propagate at the speed of light for all frames of reference. Furthermore, the impedance of free space $(Z_o)$ associated with electromagnetic radiation was found in chapter 9 to be equal to the impedance of spacetime $Z_o/\eta^2 = 4\pi Z_s = 4\pi c^3/G$.

**Electron-Positron Annihilation Thought Experiment**: We are going to develop the photon model further using a thought experiment. In this thought experiment we will look at the two entangled photons produced by annihilation of an electron-positron pair. This might seem like an exotic way of producing a pair of photons, but it actually is the simplest case to examine because unlike atomic emission or Compton scattering, no particles remain after the annihilation to carry away momentum.

We are assuming that we start with an electron-positron pair with antiparallel spin. This form of positronium typically has a lifetime of about $10^{-10}$ seconds and usually decays into two entangled photons with antiparallel spins. We will assume this normal two photon decay. These two gamma ray photons have opposite spins and opposite momentum vectors. However, the spins and momentum vectors are only defined when the first photon is detected. Each photon has 511,000 eV of energy, so the frequency and wavelength of each photon matches the Compton frequency and Compton wavelength of the annihilated rotars.

The conventional picture of this annihilation is the emission of two photons which have both particle and wave properties. The particle properties imply a packet of energy that can be found somewhere within the uncertainty volume defined by the decay time and spin orientation of the electron-positron pair. This conventional picture has the two entangled photons with opposite momentum, but the momentum directions are not set until the first photon is absorbed. At that moment the momentum and polarization of the second entangled photon has been determined. One counter intuitive part of this model is that the information about momentum and polarization must somehow be communicated to the surviving photon when the first of the two entangled photons is absorbed.

Even if the two entangled photons are separated by a distance of one light-year, they still somehow are in instantaneous communication. If one of the photons happens to interact with a polarizer of any orientation or ellipticity, the other photon instantly becomes the orthogonal polarization. Many logical questions arise from this picture. How do the two photons keep track of each other? What type of communication signal is sent out when one photon encounters a polarizer? How does this communication happen faster than the speed of light? I propose that the reason that this explanation is impossible to conceptually understand is because it is the wrong picture of a photon.

**Electron-Positron Annihilation – The Quantized Wave Model**: We will now restate this interaction using the photon and rotar models that incorporate distributed waves in the spacetime field. Suppose that we use the rotar model of an electron and a positron with opposite (antiparallel) spins that are initially far apart compared to distance $ƛ_c$. Both rotars have a Compton angular frequency of about $7.76 \times 10^{20}$ s$^{-1}$ or a frequency of $1.23 \times 10^{20}$ Hz. If these two rotars move towards each other, it means that they would both perceive the other to be Doppler shifted and the two frequencies would not be exactly the same. Since these two rotars are going to eventually emit two entangled photons of the same frequency, we will presume that the formation of positronium includes some type of synchronization of these two frequencies.

What will happen when we bring together an electron and a positron? It appears as if this interaction destabilizes both rotars. The rotar model of an isolated electron proposes that an electron is stable because there is a type of resonance between the electron's rotating dipole wave and the surrounding vacuum energy. Recall that the electron has a quantum amplitude of $A_\beta \approx 4.18 \times 10^{-23}$. This dimensionless number is also the electron's frequency, energy, mass, inverse rotar radius, etc. in Planck units. This frequency and amplitude achieves a resonance in vacuum energy that cancels the loss of power and produces constructive interference with the rotating dipole core.

The lifetime of positronium with antiparallel spins has been calculated[13] from QED as: $\boldsymbol{\tau} = 2\hbar/m_e c^2 \alpha^5 = 2/\omega_c \alpha^5 \approx 1.25 \times 10^{-10}$ s. This calculated lifetime agrees with experimentally measured lifetime. The annihilation of positronium with antiparallel spins usually produces two entangled gamma ray photons. These two photons have the same frequency, wavelength and energy as the electron and positron in the rest frame. Since the electron-positron pair had antiparallel spins, the two entangled photons also have a combined spin of zero.

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[13] http://arxiv.org/PS_cache/hep-ph/pdf/0310/0310099v1.pdf

**Photon Model of Annihilation**: Now the model of this annihilation using waves in the spacetime field will be presented. The electron and positron both have a Compton angular frequency of $7.76 \times 10^{20}$ $s^{-1}$. When these two rotars annihilate each other the stabilization mechanism with vacuum energy is destroyed. The cancellation wave formed in vacuum energy no longer prevents the dissipation of the electron's and positron's energy. Waves in spacetime at the electron/positron Compton frequency propagate away from the site of the annihilation at the speed of light. These propagating waves are two entangled photons that result from the annihilation. The waves are propagating in the medium of the vacuum fluctuations that are an essential characteristic of the spacetime field. As previously determined, the impedance and bulk modulus encountered by these waves corresponds to the impedance of spacetime $(Z_s = c^3/G)$ and the bulk modulus of spacetime $K_s = F_p/\lambda^2$. The speed of this wave propagation is equal to $c$ which was previously calculated from the interactive energy density of the spacetime field and the impedance of spacetime.

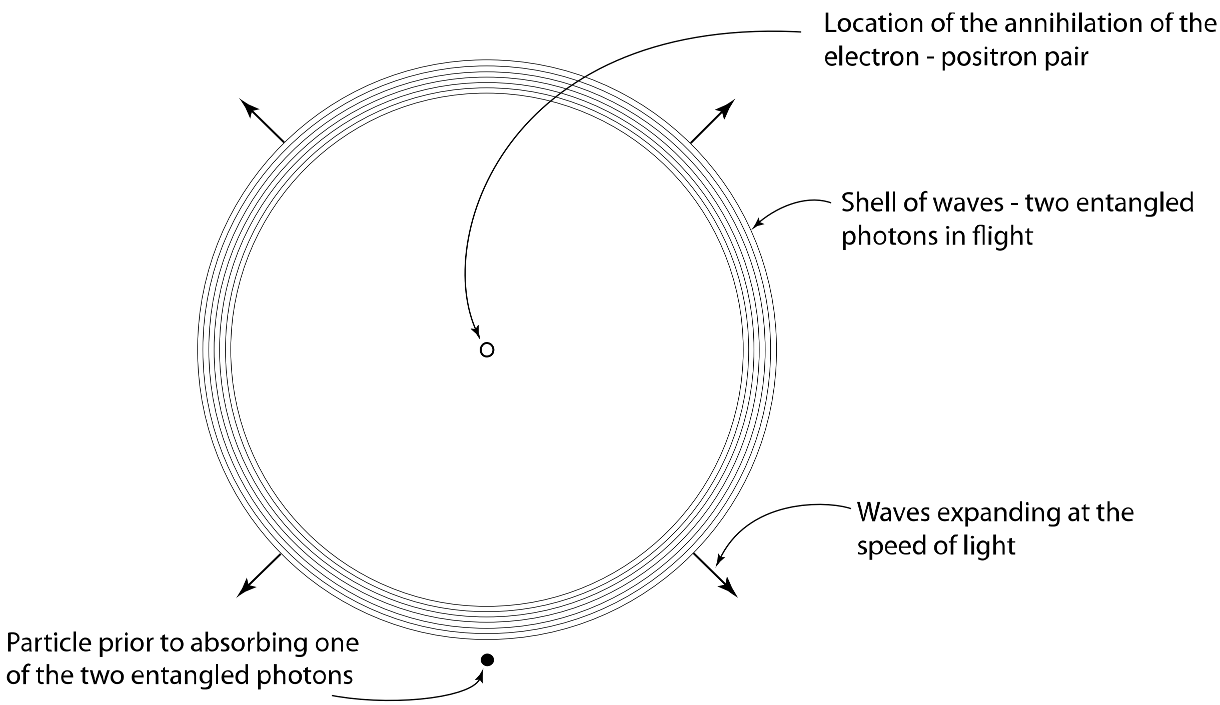


**FIGURE 11-1** Concentric circles represent the waves in spacetime that form the two entangled photons produced by the annihilation of an electron-positron pair.

Figure 11-1 shows this annihilation event. At the center of this figure, a small volume of space is labeled as the location of the annihilation of the electron-positron pair. This figure shows the results of this annihilation sometime after the annihilation takes place. This is a cross-sectional view of the waves in the spacetime field that are the two entangled photons. There is now a spherical shell of waves in the spacetime field around the annihilation volume with the radius increasing at the speed of light.

The waves in this shell have an angular frequency of $7.76 \times 10^{20}$ $s^{-1}$ which is also the electron's Compton angular frequency. Since there is no frequency change between the electron/positron and the photons emitted, the annihilation event can be considered merely the destabilization of the vacuum energy cancelation waves that were keeping the electron's energy confined. The time required for annihilation was $1.25 \times 10^{-10}$ s so this amounts to about $1.5 \times 10^{10}$ cycles (wavelengths) forming a shell of waves with a thickness of about 3.8 cm. Figure 11-1 shows multiple concentric circles to convey the idea that the expanding shell contains many wavelengths. Also the entangled spherical shell of waves has zero net spin since this example assumed that the electron and positron had antiparallel spin.

**Entanglement:** Suppose that the spherical shell of two entangled photons (propagating in the vacuum fluctuations of the spacetime field) expands into what might be called "empty space" to a radius of one light-year. Really this space is filled with a sea of vacuum energy and the waves are a disturbance in this vacuum energy. At this point, suppose that a small portion of the wave shell encounters an absorbing object that we will generically call an absorbing particle. It could be an atom or other group of rotars. To make the absorption interesting, we will presume that the absorbing material has a strong absorption preference for clockwise circular polarization at the frequency of the two entangled photons. This absorbing material is illustrated in figure 11-1 as a point labeled "particle prior to absorbing one of the two entangled photons". The absorbing particle (or group of rotars) is capable of absorbing quantized angular momentum of $\hbar$. However, the spherical shell of waves is two entangled photons that were generated when the electron and positron (both spacetime dipoles) were annihilated. The absorbing material cannot interact with only a small percentage of the quantized wave. The quantized angular momentum transferred must be either $\hbar$ or nothing.

Now it gets interesting. Any interaction must be with a complete photon (quantized energy and angular momentum). In this case, this means that the interaction is between the absorbing material and one of the two entangled photons that together made up the entire spherical wavefront, one light-year in radius. The interaction cannot be with both photons because the two photons have a total spin of zero. There appears to be a prohibition against energy transfer without an accompanying spin transfer.

If there is absorption, then the proposed property of unity causes one of the two entangled photons to collapse. All of the energy (511,000 eV), all the angular momentum ($\hbar$ of clockwise circular polarization) and all the momentum ($\sim 2.7 \times 10^{-22}$ kg m/s) of the single photon is deposited into the absorbing material. Even if the absorption happens over a finite absorption time that is comparable to a finite emission time (for example, several nanoseconds), the entire quantized wave energy, distributed over one light-year radius, must collapse in this short time.

The details of how photons are proposed to collapse will be discussed later when we deal with the eventual absorption of the second of the two entangled photons. The collapse of the first of the two entangled photons removes from the spherical shell all of the wave characteristics necessary to make a circularly polarized photon with clockwise angular momentum. This includes not only spin and energy, but the collapse also imparts momentum of $\sim 2.7 \times 10^{-22}$ kg m/s. with an accurately defined momentum vector that will be discussed later.

What remains in the spherical shell of waves are proposed to be all the characteristics required to make a photon with the orthogonal polarization (counterclockwise spin) and the opposite momentum vector which is not quite precisely defined. This implies that the second photon can only impart the opposite momentum and opposite circular polarization when it is eventually absorbed. The photon that was absorbed must be the inverse of the photon that remains since the two entangled photons originally formed a uniform amplitude shell of waves. Therefore, to obtain a description of both photons we will examine the remaining photon.

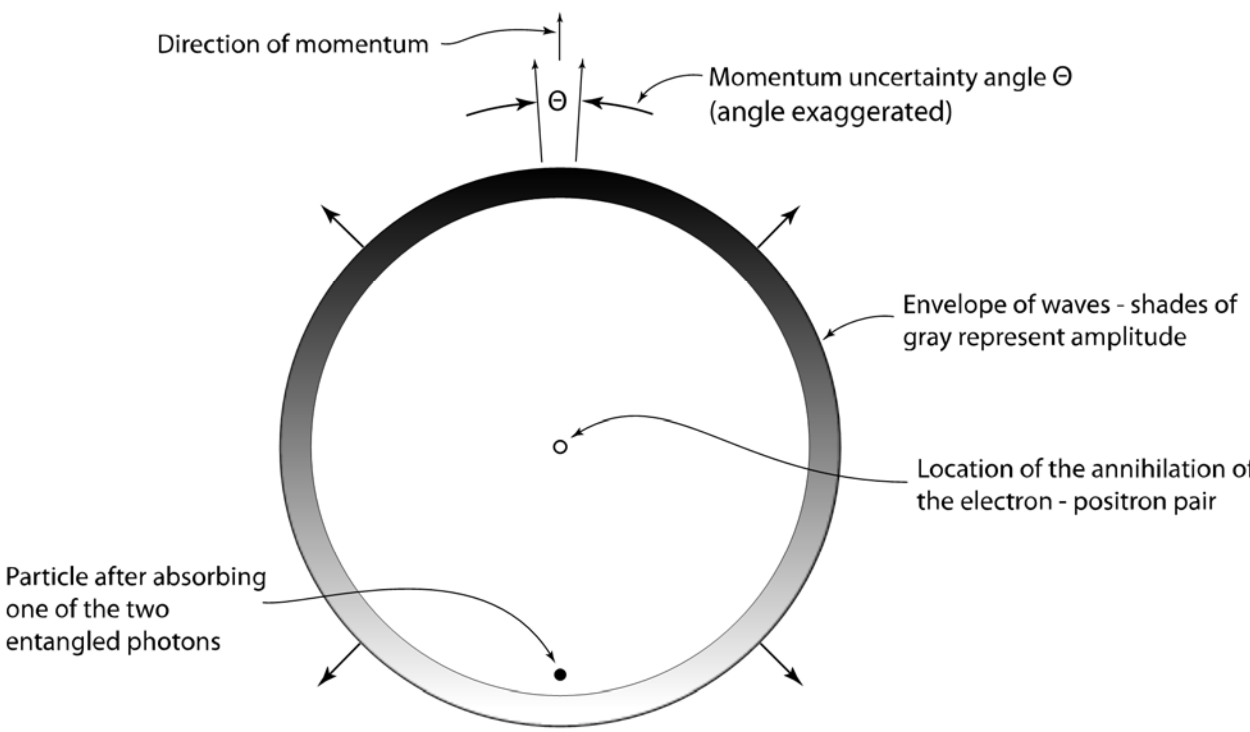


**FIGURE 11-2** Amplitude distribution (shades of gray) of the surviving photon. This is a picture shortly after the other entangled photon was absorbed by the particle shown.

**Single Photon Model**: Figure 11-2 shows the proposed model of the surviving photon after the other entangled photon previously discussed was absorbed and collapsed into the absorbing particle. In other words, figure 11-2 shows a slightly later time than figure 11-1. In figure 11-2 the envelope of waves has expanded past the particle that absorbed the other entangled photon. This particle is shown near the bottom of the figure. Compare the placement of this particle to the placement shown in figure 11-1.

The major visible difference between figures 11-1 and 11-2 is that the circle representing the envelope of waves is now shown with different shading ranging from black (highest amplitude) at the top of the figure through shades of gray to white (lowest amplitude) at the bottom of the figure. The waves are still present but the waves are not shown in figure 11-2 because the emphasis in 11-2 is the amplitude of these waves.

The amplitude distribution for the waves in the remaining photon is proposed to be the same as the amplitude distribution of the wavelets in the Huygens-Fresnel-Kirchhoff principle. Recall that the Huygens-Fresnel principle accurately models diffraction of an optical wave by assuming that all points on an advancing wavefront become the source of a new wave called a wavelet. A new wavefront is formed by coherently adding together these secondary waves, including their phases. This principle was perfected by Gustav Kirchhoff when he added an amplitude distribution to the waves that formed each new wavelet that prevented backwards propagation towards the source and improved the accuracy. Previously the wavelets were merely considered to be limited to the forward hemisphere. This arbitrary limitation worked well for most applications, but Kirchhoff's addition perfected the principle for all cases. The amplitude distribution formulated by Kirchhoff is called the obliquity factor $K(\theta)$. It can be expressed either in Cartesian or spherical coordinates. The spherical coordinate representation is: $K(\theta) = \cos^2(\theta/2)$.

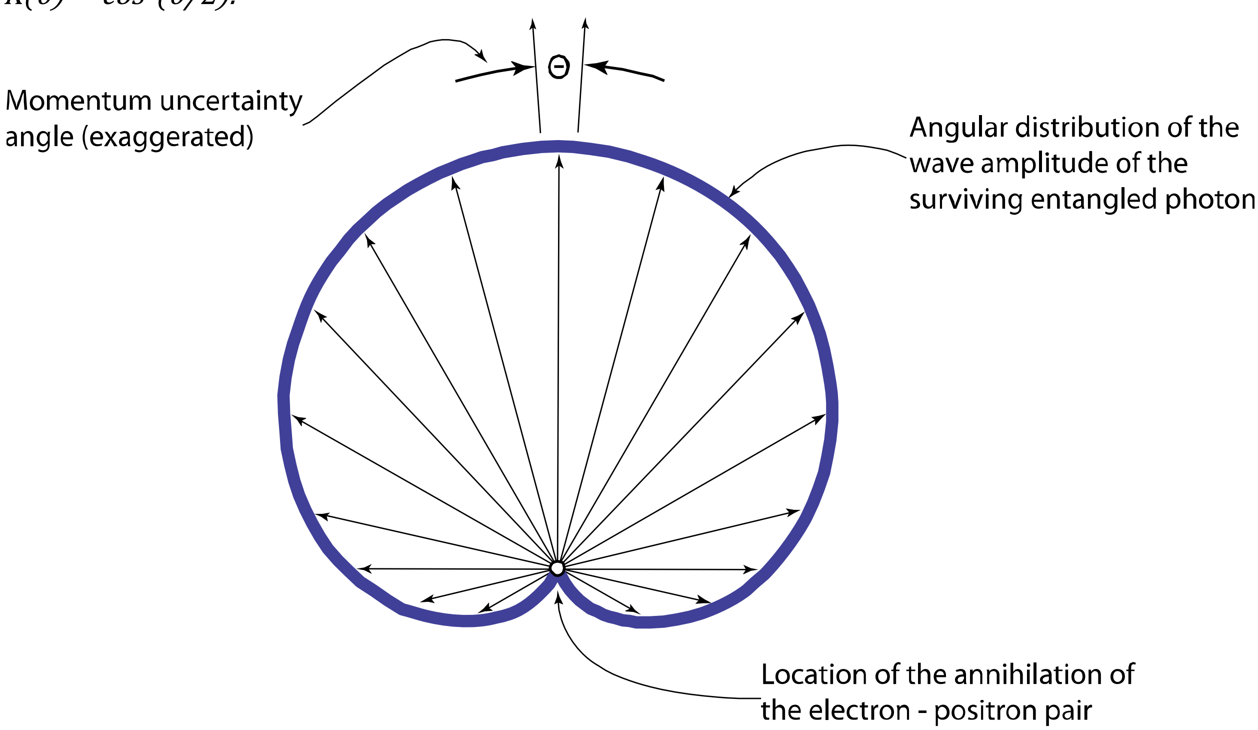


**FIGURE 11-3** Amplitude distribution (graphical representation) of the surviving photon

A single photon is proposed to have the same amplitude distribution as the wavelets required for the Huygens-Fresnel-Kirchhoff principle. The shading of the envelope of waves in figure 11-2 has this distribution. However, figure 11-3 is a graphical representation of the amplitude distribution of the surviving photon. The absorbed photon would have had the inverse of this amplitude distribution which is the same as inverting figure 11-3. Adding these two distributions together produces the uniform distribution of the original entangled pair of photons $(\sin^2(\theta/2) + \cos^2(\theta/2) = 1)$.

**Photon's Momentum**: We are now going to return to figure 11-2 to address the question of the momentum of a single photon. Recall that the thought experiment that generated this figure presumed that the two entangled photons expanded in a vacuum to the radius of one light year when finally one of the two photons was absorbed by the particle shown in figure 11-2. These assumptions mean that the momentum vector for the surviving photon must be very well defined. The original annihilation of the electron/positron pair had an uncertainty volume that can be calculated knowing the mass of the electron/positron pair ($\sim 1.82 \times 10^{-30}$ kg) and the lifetime ($\sim 1.25 \times 10^{-10}$ s) to give an emission uncertainty radius $\Delta x = \sqrt{\hbar t/2m} \approx 6 \times 10^{-8}$ m. Also the particle that absorbed the first photon could have been part of a detector that could specify the location of the absorption to a radius much smaller than the $6 \times 10^{-8}$ m uncertainty of the emission. Therefore the uncertainty in the emission dominates and we can ignore the uncertainty in defining the absorption location.

Since these two uncertainty volumes are separated by one light year ($\sim 10^{16}$ m), this means that that the momentum vector uncertainty angle of the single photon in this example is about $6 \times 10^{-24}$ radians ($6 \times 10^{-8}$ m$/10^{16}$ m). The surviving photon must have the opposite momentum, so at the moment the first photon is absorbed, we know a great deal about the allowed volume where the second photon can possibly be absorbed in the future. The reason for this exercise is that the model of a single photon must be capable of this momentum accuracy.

In figure 11-2 the envelope of waves should be pictured as being one light year in radius. This figure also shows an angular spread designated "momentum uncertainty angle" which for this example is about $6 \times 10^{-24}$ radians. How is it possible for this wave structure to possess this narrow a momentum uncertainty? Just looking at the figure, it seems as if the surviving single photon could be absorbed by an absorbing particle located in almost any direction around the expanding shell of waves (except perhaps the zero amplitude direction). The requirement of a well defined momentum helps us define the model and helps to define the way that photons collapse.

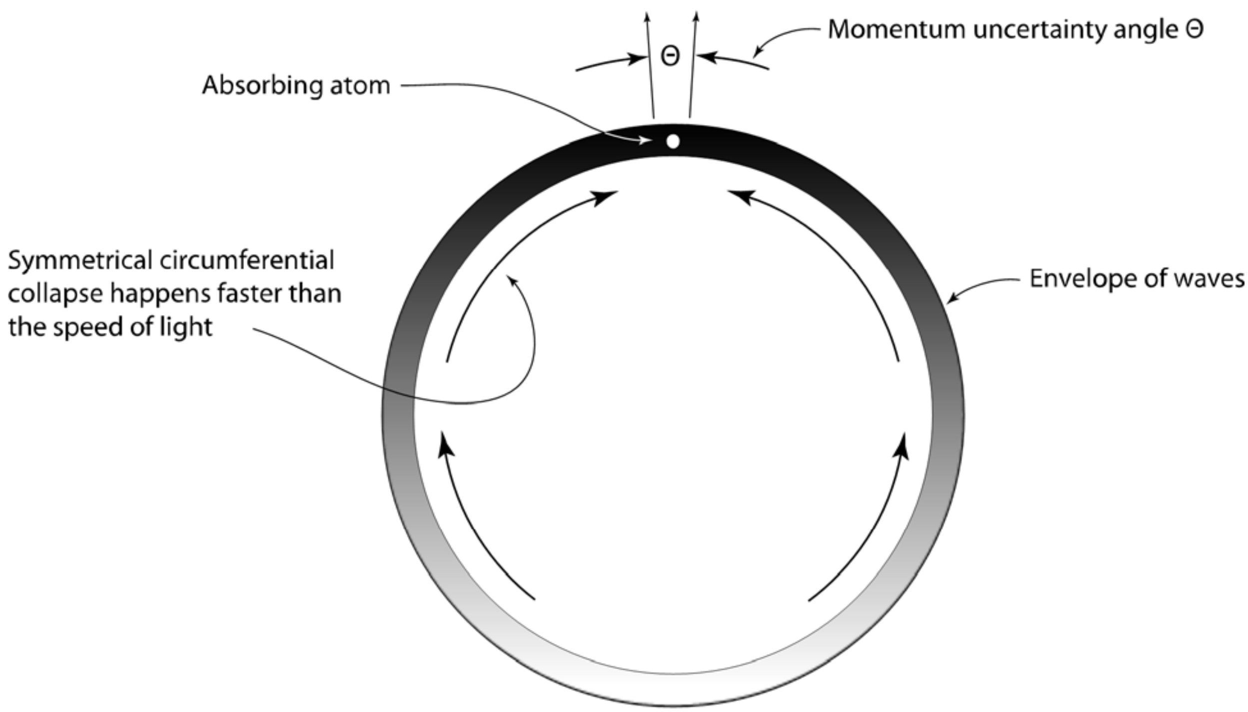


**FIGURE 11-4** The collapse of a photon on an atom

**Collapse of a Single Photon**: Figure 11-4 shows the eventual absorption of the surviving photon. The absorbing body is designated and it must lie within the volume limited in width by the momentum uncertainty angle. Also the absorbing body must be located within the thickness of the envelope of waves during the absorption. The collapse of the single photon's energy and angular momentum is depicted by the arrows shown in figure 11-4. These arrows indicate that the collapse proceeds along the circumferential route defined by the envelope of waves.

This has a great deal of appeal. The momentum transferred to the absorbing body can only have a radial vector relative to the emission uncertainty volume. It would be a violation of the conservation of momentum for there to be a tangential vector component that is larger than the uncertainty limit. This means that the only volume of the photon's wave structure capable of interacting with matter is restricted to the small volume bounded by the momentum uncertainty angle. This is the only volume where the collapse is sufficiently symmetrical to prevent the transfer of substantial transverse momentum. There must be offsetting transverse momentum components on either side of the absorbing body so that the collapse is balanced and results in the correct net momentum.

Next, we are going to examine whether the photon structure proposed here is capable of collapsing to a volume as small as would be required to satisfy the momentum uncertainty angle which is about $6 \times 10^{-24}$ radians. If the second photon was absorbed shortly after the time of the first photon absorption, then the shell of waves would be about the same size which was postulated to be 1 light year in radius ($\sim 10^{16}$ m in radius). The waves are distributed over a diameter of about 2 light years ($\sim 2 \times 10^{16}$ m) and the wavelength produced by the annihilation of an electron/positron pair is $\lambda \approx 2.4 \times 10^{-12}$ m. If we merely calculate the diffraction limit of this combination of aperture size and wavelength we obtain a $\lambda/D$ uncertainty angle (divergence angle) of $2.4 \times 10^{-28}$ radians. Therefore this wave structure can easily satisfy the requirement of collapsing to a volume equivalent to $6 \times 10^{-24}$ radians uncertainty. In fact, this photon model should always collapse to an area about one wavelength in circumference. At this point, quantized angular momentum takes over and the collapse into a single atom is possible.

**Popper's Thought Experiment:** Before proceeding with the description, we will pause and mention that the thought experiment described in figures 11-1 and 11-2 have some similarity to Popper's experiment proposed by Karl Popper and published in 1982. The Copenhagen interpretation of quantum mechanics implies that making an experimental measurement increases uncertainty. Popper wrote: "I wish to suggest a crucial experiment to *test* whether knowledge alone is sufficient to create 'uncertainty' and, with it, scatter (as is contended under the Copenhagen interpretation), or whether it is the physical situation that is responsible for the scatter". He suggested an experiment incorporating entangled particles, slits and detectors described elsewhere[14] [15]. The contention was that detecting one of the entangled particles should introduce scatter instantly communicated to the other particle if the Copenhagen interpretation was correct. An actual experiment was performed by Kim and Shia in 1999 using entangled photons[16] The conclusion was that the second of the two photons actually had a much smaller scatter (smaller uncertainty) than would be expected from the Copenhagen interpretation[17]. This experimental result supports the model of two entangled photons proposed here. As proposed in figure 11-2, the "momentum uncertainty angle" defines the uncertainty of the allowed interaction volume for the second photon. Gaining knowledge of the location of the first photon to be absorbed decreases the uncertainty about the location where the second photon will be absorbed.

**Limits on Absorption**: The portion of the single photon that lies outside the momentum uncertainty volume cannot interact with matter. The model of photons says that these waves can pass through matter (rotars) without being absorbed or affected. In the figures 11-1 to 11-4 we carefully avoided the question of the waves encountering other matter by postulating propagation in an empty vacuum. However, the waves external to the momentum uncertainty angle should merely pass through matter without any interaction. Recall that matter is made of rotars that are just empty spacetime that is very slightly strained. (roughly 1 part in $10^{20}$ for an up quark). If a disturbance in vacuum energy is incapable of transferring angular momentum

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[14] http://en.wikipedia.org/wiki/Popper%27s_experiment
[15] Popper, K.R. *Quantum theory and the schism in physics*, Routledge, 1992, p.27
[16] Y.-H. Kim and Y. Shih (1999). "Experimental realization of Popper's experiment: violation of the uncertainty principle?". *Found. Phys.* **29** (12): 1849–1861.
[17] P. Sancho (2002). "Popper's Experiment Revisited". *Found. Phys.* **32** (5): 789–805

because it is outside of the momentum uncertainty volume, then this portion of a photon should be more inert than a neutrino and should easily pass through matter (rotars).

**Unity Connection:** The circumferential collapse shown in figure 11-4 is the proposed property of unity at work. This proposed property permits faster than the speed of light communication and collapse within a single quantized wave in spacetime. In chapter 14 a speculative mechanism will be proposed for faster than the speed of light communication within a single quantized wave. However, superluminal communication is an experimentally established property of entanglement and it is quite reasonable that a single photon would also possess this same capability even if the complete explanation is not currently available. The superluminal collapse of a photon shown in figure 11-4 is symmetrically balanced and does not involve the transfer of any information or external momentum. The momentum that is transferred is entirely within the single photon. While the collapse is faster than the speed of light, it is not instantaneous. It probably requires a time of at least $2\pi/\omega$ which is a minimum of one cycle of the photon.

It is also clear that there is no mystery how the photon model can carry angular momentum. The shell of waves must be pictured as a 3 dimension spherical shell. The waves that make up a circularly polarized photon would have a phase progression that circulates the spherical shell at a frequency equal to the photon's frequency. Figure 10-9 in chapter 10 showed waves in the equatorial plane of the external volume of a rotar. It is obvious that waves forming an Archimedes spiral carry angular momentum. It is proposed that a circularly polarized photon has a similar Archimedes spiral wave distribution in the equatorial plane. The spatial distribution of this shell of waves makes it easy to see how it is possible for this photon model to carry angular momentum and transfer the angular momentum when the wave structure collapses onto an absorbing body. It is not clear how the conventional model of a photon carries or transfers angular momentum.

**Photon Emission from a Single Atom**: In the thought experiment involving the annihilation of an electron/positron pair there was no remaining matter to remove momentum and complicate the analysis. We will next address the emission of a photon by a single atom. If a proton and an electron combined to form a hydrogen atom, the energy of the photon emitted would be about 13.6 eV. The emission of this energy would cause the hydrogen atom to recoil with a velocity of about 4 m/s. Hypothetically, it is possible to determine the direction of the photon's momentum by monitoring the motion of the electron and proton prior to forming the hydrogen atom and by monitoring the recoil of the hydrogen atom after the emission of the photon. There is uncertainty in making these measurements, but the accuracy in determining the direction of the photon's momentum increases with the amount of time between emission and detection of the recoiling atom. The photon has the opposite momentum of the recoiling hydrogen atom. The further the recoiling hydrogen atom travels before its position is detected, the more accurate that the momentum vector of the recoiling hydrogen atom can be determined.

The photon is carrying the opposite momentum vector as the recoiling hydrogen atom to within the limits of the uncertainty principle. I claim that not only does our ability to measure the momentum vector of the recoiling hydrogen atom improve with time, but there is continued interaction between the external volume of the recoiling hydrogen atom and the photon even after the photon has been emitted from the atomic volume of the hydrogen atom. The hydrogen atom is surrounded by waves that are part of the external volumes of the rotars that form the atom. As the photon spherical shell expands, it interacts with these external waves and this interaction fine tunes the momentum uncertainty vector of the expanding photon. This interaction reduces the momentum uncertainty angle of the expanding photon over time to coincide with the improved ability to measure the recoil momentum vector of the hydrogen atom.

**Compton Scattering Revisited**: A hydrogen atom made of 4 rotars (1 electron and 3 quarks) is too complicated to analyze the interaction between the expanding photon and the external volume of the rotars that form the hydrogen atom. Therefore we will switch back to Compton scattering between a single electron and a single photon. This interaction was previously examined using the series of figures from 10-12 to 10-15. Figure 10-15 is the superposition of 4 waves. The waves at the top of this figure represent the photon's waves before and after the scattering. The waves at the bottom of the figure represent the electron's waves before and after the scattering. The middle portion of the figure shows both pairs of waves interacting.

Because of the standing waves in the electron's external volume this interaction continues to occur long after we think that the scattering event has happened. Picture the electron (rotar) as having diminishing standing waves in its external volume that extend a long way from the location of the scattering. The "news" that the rotar has undergone acceleration propagates into these surrounding standing waves at the speed of light. There is a spherical shell that is expanding at the speed of light where the overlap of the before interaction and after interaction waves overlap. Within this expanding shell of overlapping waves, the fringe pattern shown at the top of figure 10-15 still exists, but at greatly reduced amplitude. This is superimposed on the photon's waves which are also spreading away from the scattering site at the speed of light. The interaction between these overlapping waves continues to make successively finer adjustments to the photon's momentum. This explains how the uncertainty of the photon's momentum can improve over time, just like we reasoned by looking at the recoil of a hydrogen atom.

In all of this, the electron does not undergo a gradual acceleration as might be expected for a classical particle that is changing its momentum. Instead, the wave model of the scattered rotar changes from the wave pattern of the rotar before the scattering to the wave pattern of the rotar after the scattering without undergoing the intermediate velocities. Similarly, a hydrogen atom would not gradually accelerate to 4 m/s as it emits a 13.6 eV photon. The "before" wave pattern fades as the "after" wave pattern comes into existence.

From the uncertainty principle we know that a decrease in the momentum uncertainty ($\Delta p$) must be accompanied by an increase in the position uncertainty $\Delta x$. When we think of a point particle photon, then the physical interpretation of $\Delta x$ is different than when we think of a single photon as a shell of waves with a large radius. To accommodate this improvement in our knowledge of the photon's momentum (decreased $\Delta p$), it is necessary for the radius of the photon to increase with time (increased $\Delta x$). This requirement fits perfectly with the proposed photon model because the radius of the photon's shell of waves increases with time.

**Recoil from Coherent Emission**: In the above examples, it was repeatedly emphasized that they described the properties of a single photon. The characteristics of photons change dramatically when they congregate into coherent beams. We are going to ease into a discussion of a beam of light made of many photons with the following preliminary thought experiment.

Suppose that we have a rotating electrically charged dipole. This imagined electrically charged dipole is made of a positive charge and a negative charge physically separated by a short rod. For example, imagine an electron and a positron separated by a rod 1 mm long and rotating about a perpendicular axis at the center of the rod at a frequency of $10^{10}$ Hz. Even though it would be virtually impossible to have this electrical dipole mechanically rotate at this frequency, in the thought experiment there is no such limitation. We would expect to see the emission of microwave electromagnetic radiation ($10^{10}$ Hz) in a classical rotating dipole emission pattern from this rotating dipole. This pattern has emission in all directions, but the intensity of emission is twice as strong along the rotation axis as the intensity in the equatorial plane. However, near the equatorial plane there are more ster-radians for emission so all emission directions are important. The classical rotation dipole radiation pattern is symmetrical around the axis of a mechanically rotating dipole. This pattern is really the result of the emission of many incoherent photons. This symmetrical emission pattern does not produce recoil in any particular direction.

Now suppose that we have a trillion such rotating dipoles distributed over a spherical volume with radius about 1000 times larger than the microwave emission wavelength. The dipoles are therefore distributed in a way that individual dipoles are separated from their nearest neighbor by much less than one wavelength but the group is much larger than a wavelength. If the rotating dipoles are all rotating incoherently, they emit incoherent radiation in all directions. Since the emission is symmetrically balanced, there is no net recoil direction felt by individual rotating dipoles.

However, if all dipoles are rotating coherently (same frequency, parallel rotation axis and controllable phase) the radiation from the group of rotating dipoles can be controlled. For example, the microwave radiation can be made into a diffraction limited beam that can be steered in any direction. This directional control depends entirely on the ability to adjust the phase of individual dipoles in the group so that the multiple emissions add constructively in the desired emission direction.

Now let's think about the recoil felt by each mechanically rotating dipole from the emission of radiation. If only one dipole is mechanically rotating, the emission of multiple photons (photons) is symmetrical and no specific recoil direction is felt by the single rotating dipole. However, when the multiple rotating dipoles are properly phased to constructively interfere in a particular direction, then each rotating dipole must feel a force in the opposite direction as the emitted beam. We would say that this force is the momentum recoil required for conservation of momentum. However, each rotating dipole is just interacting with the local EM field generated by the coherent addition of spherical waves generated by other rotating dipoles. The collimation and directionality of the emitted beam is achieved by the group interaction. The point is that the emission direction and the recoil direction are the result of the coherent addition of properly phased rotating dipoles.

**Huygens-Fresnel-Kirchhoff Principle**: At this point the analysis converts to a classic example of the Huygens-Fresnel-Kirchhoff principle. With this principle, each point on a wavefront becomes the source of a new wavelet that emits into the amplitude distribution formulated by Kirchhoff: $\cos^2(\theta/2)$. This is exactly the same emission pattern as a photon with its momentum vector aligned with the beam vector. Therefore each cycle of the coherent photon emission is identical to the wavelet that would be formed at the location of the emitting rotating dipole. The Huygens-Fresnel-Kirchhoff principle describes amplitude addition and how intensity is proportional to the square of amplitude. Therefore, the individual photon joins the beam as if it was merely a series of new wavelets. The only difference is that in the Huygens-Fresnel-Kirchhoff principle the total energy of the beam remains constant while the emission of a coherent photon increases the total amplitude and energy of the beam.

It is a short step from mechanically rotating dipoles to many atoms in an excited state in a laser gain medium. The propagation of a laser beam is well described by the Huygens-Fresnel-Kirchhoff principle. Each point on the laser beam becomes a new wavelet and the beam evolves by coherent addition of successive generations of wavelets. When a laser beam passes through a laser gain medium, it interacts with atoms in an excited state. The interaction not only stimulates the emission of photons with the proper frequency and phase, but the interaction also imparts the correct recoil to the atoms so that the photons are emitted with the correct momentum vector. The addition of new photons to the laser beam then corresponds to the wavelet addition of the Huygens-Fresnel-Kirchhoff principle.

**Beam of Light**: How can the model of a single photon (spherical shell of waves with a Kirchhoff amplitude distribution) be reconciled with the concept of a well behaved beam of light that can be easily reflected off mirrors and brought to a focus? A beam of laser light does not seem to have any of the properties of a spherical shell of waves just described. However, the photon model for a single photon is different than the photon model for many interacting photons. Many interacting photons are better described by the Huygens-Fresnel-Kirchhoff principle which incorporates wavelet addition from the other photons. Each photon does have a momentum uncertainty angle set by the recoil felt by the emitting atom. The group behavior is limited to photons which have a momentum uncertainty angle which permits propagation in the direction of the rest of the beam. Therefore, there is a limit to the amount of steering that can occur by the rest of the photons. If a photon was emitted with an uncertainty angle at too steep of an angle relative to the direction of the rest of the beam, then that photon will merely exit the beam.

For example, a 1 mw HeNe laser beam contains about $3 \times 10^{15}$ photons per second. Multiple photons, such as a laser beam, together achieve the familiar beam of light. Even though each individual photon would propagate into a spherical shell of waves previously described, the interaction with the other photons in the beam causes a group behavior described by the Huygens-Fresnel-Kirchhoff principle. For example, the intensity scales as amplitude squared and the only amplitude that counts is the amplitude within the momentum uncertainty angle for each photon. These conditions achieve the familiar properties of a beam of light. Still, the generation of wavelets implies that the photons are exploring every possible path between two points as required by the path integral. Furthermore, there is a presence outside the volume that appears to be the diameter of the beam. Even though the portions of waves that exist outside the beam volume lack the ability to strongly interact with matter, is there any proof that these "external" waves must exist?

The answer to this question is yes. Light is a form of energy and therefore a beam of light must cause a gravitational field (curved spacetime) in the surrounding volume. It is not sufficient to cite "curved spacetime" and claim to have proved that light causes gravity. When we adopt the assumption that the universe is only spacetime, the implication is that everything is knowable including the mechanics of light causing curved spacetime. The gravity and electric field of fundamental particles was explained as being caused by standing waves in the external volume of the particle. Wave frequency, amplitude and nonlinear effects were derived. Similarly, a beam of light causes gravity in the surrounding volume. How is this accomplished? If we think of a beam of light as a stream of particle-like photons (a bundle of quantized energy that lacks rest mass), then there is no mechanism to create gravity in the surrounding volume. Also there is no mechanism for the light to explore all possible paths between two points as required by the "path integral". However, if we think of light as a wave disturbance in spacetime with each wave becoming the source of new wavelets, then there is a mechanism to explain both the gravitational field and the physics behind the path integral. As previously explained, these waves extend beyond the momentum uncertainty volume which defines the limit where photons can interact with matter.

Normally I would do a plausibility calculation here to show that the proposed photon model resulted in the correct gravitational field. For example, if we imagined many photons ($n_\gamma$ photons) in maximum confinement, then this "confined energy" propagating at the speed of light would exhibit rest mass as described in chapter 1. An analysis of photons in maximum confinement could also be made to look something like a rotar. It was already demonstrated how a rotar with internal energy $E$ produces the correct gravitational field for this energy. However, neither of these are exactly applicable because the maximum confinement volume of many photons has a different radius than a single rotar of equal energy. An analysis of this subtlety is incomplete and off the main point. It will merely be stated that the proposed photon model does extend into the surrounding volume. Furthermore, it appears to have the correct properties to create both the required gravitational field and the ability to explore all possible paths. The mathematical proof of this will have to be left to others.

**Why Is there No Amplitude Dependence In a Photon's Energy?** One of the mysteries of quantum mechanics is contained in the photon's energy equation $E = \hbar\omega$. Why does this equation only contain the frequency term $\omega$ with no amplitude term? If two different waves have the same frequency but different amplitudes, they should have different energy. Can the spacetime based model of photons answer this century old mystery of physics?

The maximum displacement of the spacetime field allowed for a dipole wave in spacetime is subject to the previously discussed Planck length/time limitation. While a photon is not technically a dipole wave in the spacetime field, it is produced and absorbed by dipole waves in spacetime. A single photon inherits a connection to Planck length and Planck time. As previously shown, multiple photons can produce a distortion of the spacetime field that appears to exceed the Planck length/time limitation. However, the round trip change in distance does not actually exceed this limitation. The strain amplitude of a single photon in maximum confinement is $A_s = L_p/\lambda\!\!\!^{-}$. We will calculate the energy of a photon in maximum confinement using $E = A^2\omega^2 ZV/c$.

$E = A^2\omega^2 ZV/c$ set: $A = A_s = L_p/\lambda\!\!\!^{-}$, $\omega = c/\lambda\!\!\!^{-}$, $Z = Z_s = c^3/G$ and $V = \lambda\!\!\!^{-3}$

$$E = \left(\frac{\hbar G}{c^3\lambda\!\!\!^{-2}}\right)\omega^2\left(\frac{c^3}{G}\right)\left(\frac{\lambda\!\!\!^{-3}}{c}\right) = \hbar\omega$$

Therefore, the amplitude term disappears and we are left with $E = \hbar\omega$. It is easy to see how this happens. As previously explained, there are two types of amplitude: displacement amplitude and strain amplitude. The displacement amplitude for photons in maximum confinement is always equal to dynamic Planck length $L_p$. The strain amplitude ($A_s = L_p/\lambda\!\!\!^{-}$) is used in the energy equation, but the strain amplitude incorporates the displacement amplitude. The fact that all photons produce the same displacement of the spacetime field makes it possible for cancelations to eliminate amplitude from the energy equation. However, in another sense, the presence of $\hbar$ is a remnant of amplitude term because: $A_s^2 = L_p^2/\lambda\!\!\!^{-2} = \hbar G/c^3\lambda\!\!\!^{-2}$. Everything cancels from the amplitude squared term except for $\hbar$. In one sense $\hbar$ is the amplitude term because it is the amplitude of the quantized angular momentum.

**Requirements of a Photon Model:** A carbon monoxide molecule (CO) is a good source of photons if we are attempting to understand photons. CO has a carbon atom and oxygen atom separated by about $1.1 \times 10^{-10}$ m. It is a polar molecule since it has a nonzero permanent electric dipole moment. Experiments have shown that the carbon atom is negatively charged and the oxygen atom is positively charged. This charge distribution is the opposite of what might be expected from chemical valences. The CO molecule can rotate around its center of mass axis perpendicular to its bond length. The CO molecule can only possess integer multiples of $\hbar$ angular momentum. (J = 0, 1, 2, 3 etc.) The fundamental rotational frequency is about 115 GHz and higher rotational frequencies are approximately integer multiples of this frequency. The higher frequencies are not exact multiples of 115 GHz because the physical rotation of the molecule slightly stretches the bond length because of centrifugal force. The CO molecule also has vibrational energy levels. This is all mentioned because the rotating polarized molecule will be useful in visualizing the model of a photon. The emission or absorption of a photon is always accompanied by an $\hbar$ change in angular momentum of the rotating molecule. All photons, even linearly polarized photons, must possess $\hbar$ of angular momentum. Furthermore, this angular momentum that is transferred between the CO molecule and a photon is not a random rotational direction. For example, the emission of a photon, even a linearly polarized photon, must always remove $\hbar$ of angular momentum and slow down the rotation of the CO molecule by $\hbar$ (one "J" unit).

Conventional models of photons do not explain how linearly polarized photons can possess angular momentum. For example, if we take a rotating polarized molecule as the source of photons, then the emission pattern for rotating dipoles has linearly polarized photons emitted in the equatorial plane and circularly polarized photons emitted from both poles. Elliptically polarized waves are emitted in all other directions. All the emitted photons, regardless of polarization, are each removing $\hbar$ of angular momentum. This is a requirement to preserve the conservation of energy and momentum. Also, photons transfer $\hbar$ of angular momentum when they are absorbed. For circularly polarized photons, the rotational axis is parallel to the propagation direction and it is easy to do experiments that demonstrate that circularly polarized photons carry angular momentum.

For linearly polarized photons the angular momentum should have a rotational axis that is perpendicular to both the propagation direction and the plane of the electric field. In other words, the rotational direction should have its axis in the photon's magnetic plane. It should be possible to do an experiment that demonstrates this. I have some ideas on this point, but a description of possible experiments would be long and beyond the scope of this book. The point of this is that any model of a photon must be able to explain how individual linearly polarized photons must be able to transfer angular momentum with the axis parallel to the magnetic field.

**Angular Momentum of a Circularly Polarized Photon**: It is possible to experimentally demonstrate that circularly polarized light possesses angular momentum. For example, the mineral mica is optically birefringent. A thin sheet of mica of a particular thickness can have the ability to reverse the direction of rotation of circularly polarized light. Another way of saying this is that mica can form a half wave plate. If a very small piece of mica is suspended with low friction, (for example in a liquid) then shining a circularly polarized laser beam at the mica chip will cause the mica to rotate in the liquid. The photon's angular momentum is being reversed by the mica. This transfers angular momentum from the photons to the mica and causes the mica to rotate. No photons are being absorbed, but the frequency of the transmitted photons is being lowered slightly by the interaction with the rotating mica. This reduction in frequency is equal to twice the rotational rate of the mica. This loss of photon energy provides the energy required to rotate the mica.

The absorption of a circularly polarized photon by an absorbing object imparts both a translational momentum component $p = E/c = m\boldsymbol{v}$ and an angular momentum component. The angular momentum component can be expressed as $\boldsymbol{L} = r \times m\boldsymbol{v}$ which is the cross product of the translational momentum component $m\boldsymbol{v}$ and the radius $r$ relative to the axis of rotation. Imagine that we have a polarized diatomic molecule with two atoms, each with mass of $m/2$. The bond between the atoms approximates a rigid rod that maintains a constant separation distance of $2r$ between the atoms. All molecules can only possess integer multiples of $\hbar$ angular momentum. This translates into the molecule only being able to rotate around its center of mass (distance $r$ from each atom) at a fundamental angular frequency $\omega_f$ and integer multiples of this frequency. We are going to make a calculation of the translational momentum ($p_t$) imparted to the molecule as it recoils from absorbing a photon of frequency $\omega_f$ (with wavelength $\lambda\!\!\!^{-}_f = c/\omega_f$) and compare this to the rotational momentum ($p_r$) imparted to the molecule by the photon causing the two atoms to revolve around the center of mass.

$$p_t = \frac{E}{c} = \frac{\hbar\omega_f}{c} = \frac{\hbar c}{\lambda\!\!\!^{-}_f\, c} = \frac{\hbar}{\lambda\!\!\!^{-}_f} \qquad p_t = \text{translational momentum}$$

$$p_r = \frac{\hbar}{r} \qquad p_r = \text{rotational momentum}$$

$$\frac{p_r}{p_t} = \frac{\lambda\!\!\!^{-}_f}{r}$$

This is a very interesting result. For all molecules, $\lambda\!\!\!^{-}_f \gg r$. Therefore, the momentum transferred to cause rotation $p_r$ is much larger than the momentum transferred that causes translation $p_t$. We will use a carbon monoxide molecule (CO) to examine this point. This molecule is electrically polarized (C and O atoms oppositely charged) so when it rotates it is a rotating dipole. The molecule can possess rotational angular momentum in integer multiples of $\hbar$. For example, one $\hbar$ unit is designated J = 1 and two units of $\hbar$ is J = 2, etc. At the fundamental rotational frequency (J = 1) the molecular rotation frequency is 115 GHz and the photon associated with the transition of J = 0 to J = 1 is a photon with frequency of 115 GHz. The CO molecule is a rotating dipole and the emission frequency corresponds the frequency difference between rotational states. The photon emitted going from J = 2 to J = 1 is 230 GHz, twice the frequency emitted going from J = 1 to J = 0.

To illustrate a point, we will be using the fundamental transition at 115 GHz which corresponds to the fundamental angular frequency of $\omega_f \approx 7.2\times10^{11}$ $s^{-1}$ and a reduced wavelength of $\lambda\!\!\!^{-}_f \approx 4\times10^{-4}$ m. If the molecule is carbon 12 and oxygen 16, this is not quite equal weight atoms as assumed in the calculation, but it is close enough that an approximate calculation will still illustrate the point. Even though the electron clouds partially overlap, this molecule has the carbon atom nucleus and oxygen atom nucleus separated by about $r = 1.1\times10^{-10}$ m. Therefore the radius to the center of rotation (compensating for slightly different masses) is $r \approx 5\times10^{-11}$ m. Therefore the ratio of $\lambda\!\!\!^{-}_f/r \approx 8\times10^6$. This says that the momentum required to cause the increase in rotation velocity is about 8,000,000 times greater than the momentum transferred which causes the increase in translation velocity (recoil velocity). Transferring $\hbar$ of angular momentum requires a much larger force (momentum times interaction time) than transferring the translational momentum.

We will check this surprising result to see if it is reasonable. We know that the molecule is spinning at 115 GHz when it has absorbed $\hbar$ of angular momentum (J = 1 state). If the radial distance is $r \approx 5\times10^{-11}$ m, then 115 GHz rotation frequency produces a circumferential velocity of about 36 m/s. The CO molecule has mass of m = $4.65\times10^{-26}$ kg. Absorbing a 115 GHz photon (E = $7.6\times10^{-23}$ J) produces a recoil velocity (v = E/mc) of about $5\times10^{-6}$ m/s. Therefore, the ratio of the recoil velocity to the rotational velocity (36 m/s vs. $5\times10^{-6}$ m/s) is indeed about 8,000,000.

This exercise raises an important question. If the full momentum carried by the photon is only able to achieve a velocity of $5\times10^{-6}$ m/s, this is totally inadequate to achieve the transfer of $\hbar$ of angular momentum and accelerate the two atoms (C and O) to a rotational frequency of 115 GHz requiring a rotational speed of about 36 m/s. This insight is revealing something important about how a photon interacts with a molecule or atom. To achieve the rotational velocity of about 36 m/s it is necessary to understand what force the photon uses to apply about 8,000,000 times more momentum than the photon is carrying.

As previously discussed, these transitions are not instantaneous. They last for a time period that is equal to the inverse bandwidth of the emission or absorption. Therefore, somehow a force is being generated that is about 8,000,000 times greater than the force obtained by dividing the momentum by the application time. There is one possibility that will be examined. The CO molecule is polarized meaning that there is charge separation. When a rotating dipole such as a CO molecule generates a photon, the accelerated charge generates a rotating electric field which changes from the near field pattern to the far field patter which eventually results in propagating transverse electromagnetic waves. The point is that rotating electric fields are responsible for the generation of the photon. The emission of a circularly polarized photon must generate an electric field which retards the rotation because the CO molecule must lose energy and drop one $\hbar$ quantum of angular momentum (for example J = 1 to J = 0). It is quite reasonable that the mechanical process of absorbing the same frequency photon is the reverse of the emission process. In other words, the absorption of a circularly polarized photon generates a rotating electric field. It is the electromagnetic coupling of the rotating electric field and the oppositely charged atoms which permits a force about 8,000,000 times larger than the momentum force ($F = p/t$). This coupling transfers $\hbar$ of angular momentum to a CO molecule and changes the rotational energy level from, for example, J = 0 to J = 1.

The suggestion being made is that the absorption of a photon is interacting with the CO molecule in two different ways. The relatively large force that is increasing the rotational velocity of the CO molecule is the result of the collapsing photon's electric field causing the rotation of the charged atoms to increase. To accomplish this the collapsing photon must generate a rotating electric field with the proper characteristics of phase, orientation, etc. A calculation has been made (not shown here) which shows that an electric field comparable to the electric field present in a CO molecule could easily achieve the transfer of $\hbar$ of angular momentum even if the absorption time is assumed to be the shortest possible time – about $9\times10^{-12}$ second, which is 1 cycle of a 115 GHz photon. Normally the transfer would take place over a much longer time (many cycles).

However, this exercise does show one additional defect in the conventional model of a photon transferring energy from one molecule to another. If spacetime is an empty void and if a photon is a compact packet of energy with probability waves, then how does such a photon generate 8,000,000 times more momentum in the rotational direction than the linear momentum being carried by the photon? This is not a violation of the conservation of angular momentum if you merely look at the photon carrying $\hbar$ of angular momentum and the molecule gains $\hbar$ of angular momentum upon absorbing the photon. However, the problem appears when you try to explain the origin of the force applied over the time required to transfer the angular momentum to the molecule. A favorite trick is for a physics teacher to explain to a student that the photon possesses "intrinsic angular momentum" – end of discussion. The implication is that the student and all other humans are not intelligent enough to understand the physical processes which produce quantum mechanical effects.

When an isolated atom or molecule emits a photon, the wavelength of the photon is typically 1,000 to 100,000 times larger than the radius of the atom or molecule. For example, a rubidium atom has a radius of about $2.3\text{x}10^{-10}$ m and the D2 resonance wavelength is 780 nm. Therefore, the emitted wavelength is about 3400 times larger than the atomic radius. We are not particularly surprised that this small an atom can emit a much larger wavelength photon. The previously cited article titled "How a Photon is Created or Absorbed" shows that the wave properties of the two orbitals beat at the emission frequency of the photon for a time period equal to the emission time. For the Rb emission example, the emission takes about 26 ns. The absorption process is the reverse of the emission process. There is not an instantaneous collapse. The orbitals beat for about 26 ns and the photon's waves collapse into the atom.

Similarly, an isolated CO molecule has a beat between the wave properties of the two different rotational rates with angular frequency $\omega = 115\times10^{9}$ $s^{-1}$. The relatively long wavelength of $\lambda\!\!\!^{-} \approx 0.4$ mm reverses the emission process collapses into a much smaller CO molecule with radius of about 1.4 Angstroms. The point is that the energy density of spacetime permits the process to generate the necessary torque to transfer the necessary angular momentum. Recall in chapter 4 we calculated the bulk modulus and interactive energy density of spacetime. The properties of the spacetime field have no problem generating torque beyond the force implied by the photon's momentum.