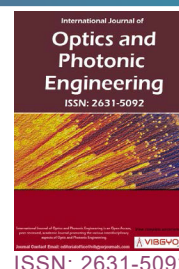




# Intrinsic Properties of the Photon



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## Abstract

Expressions for the time dependence of the amplitude of electric and magnetic field components are generalized and analyzed for various wavelengths of light. The amplitudes of the fields, as well as the frequencies and wavelengths of light, are determined by intrinsic energy, which are dictated by the electronic transition energies that cause its emission. Various features of light are responsible for its interaction with matter, such as the extent of penetration into, as well as the refractive index of, translucent materials through which light propagates. Evidence is provided for estimating the physical size of a single photon. What may be called synchronous aberration of light is described at the photon level when detectors and sources are in uniform motion.

## Keywords

Synchronous aberration, Photon characteristics, EM photon tracings

## Introduction

Light is composed of miniscule corpuscles (Newton), photons (Lewis), or quanta (Einstein) of energy that propagate forward at rapid intrinsic speed  $c$  (Maxwell, Hertz, Michelson) with perpendicular electric and magnetic field sets that self-induce and self-annihilate each other according to laws of induction that trace patterns of waves (Young) through space. James Clerk Maxwell mathematically demonstrated that the light photon electric and magnetic fields have maximum amplitudes  $E_0$  and  $B_0$ , that trace out sinusoidal trigonometric patterns as a function of time while propagating through space at speed  $c = E/B = 1/(\epsilon\mu)^{1/2}$  from the location in space at which it departs its source [1]. Electric

and magnetic fields are vector quantities listed in bold. Light speed  $c$  in vacuum is approximately  $3 \times 10^8$  m/s for all wavelengths. This mathematically derived speed for light by Maxwell [2] was initially confirmed experimentally when Hertz [3] computed wavelength multiplied by frequency for EM radiation generated in the laboratory (where  $c = f\lambda$ ), and then directly in physical measurements of light speed conducted by Albert Michelson for a 44 mile roundtrip of travel in the San Gabriel Mountains, Southern California.

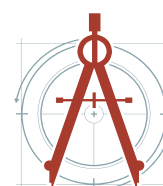
The energy that a given photon of light contains is given by  $E = hf = hc/\lambda$  where  $h$  is Planck's constant,  $f$  is the frequency, and  $\lambda$  the wavelength of light. Light has no mass [4]. Light energy is exactly

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half electric and half magnetic, where  $E = (1/2)eE^2 + (1/2)B^2/u$  so that  $eE^2 = B^2/u$  [1]. From these facts, expressions for the amplitudes of the electric and magnetic fields that propagate through space as a function of time are analyzed. Graphs of blue and red light are shown to demonstrate the rates at which energy density propagates forward for various frequencies of light which may help determine the mechanism by which light affects the refractive index and depth of penetration through translucent media. Vector quantities are in boldface, variables and units of measurement are italicized.

## Methods

The trigonometric sine function represents the ratio of the vertical height or a right triangle divided by the hypotenuse. In the unit circle, as the angle from the horizontal increases from 0 to 360°, sine values vary from 0 to 1 to -1, and return again to 0, and these values cycle repeatedly *ad infinitum* as the angles progress. Therefore the sine function has been used to describe the behavior of light [5] that propagates through space while the electric and magnetic fields vary cyclically and trace this type of wave pattern. The coefficient of the sine function that represents the maximum amplitude of the electric or magnetic field components were obtained from the derived expressions for light energy, where  $E_o = (E/\epsilon)^{1/2}$  and  $B_o = (Eu)^{1/2}$  [1], where  $\epsilon$  and  $u$  are the electrical permittivity and magnetic permeability of space. Although half of a photon energy is electric field energy, the energy is not divided by 2 here because the maximum amplitude  $E_o$  is twice the average amplitude. Therefore a function that describes the variation in electric and magnetic field amplitudes that are traced out by a photon of light may be represented by:

$$E(t) = (E/\epsilon)^{1/2} \sin[(E/h)t] \quad (1)$$

$$\text{and } B(t) = (Eu)^{1/2} \sin[(E/h)t] \quad (2)$$

Where  $h$  is Planck's constant at  $6.63 \times 10^{-34}$  J-s. It is assumed for clarity that when a photon is released from its source that a photon begins with initial values for  $E$  and  $B$  of zero at time  $t = 0$ . The energy of 450 nm blue light considered here is  $4.4 \times 10^{-19}$  J/photon (264 kJ/mole), green is  $3.6 \times 10^{-19}$  J/photon (217 kJ/mole), and 700 nm red light is  $2.8 \times 10^{-19}$  J/photon (168 kJ/mole). Graphs of wave functions traced out by red and blue photons were constructed on the Desmos Graphics application. Note that the intrinsic speed that light must have at all

times from the location in space at which it is produced is the ratio of these expressions, where  $c = E(t)/B(t) = [(E/\epsilon)/(Eu)]^{1/2} = 1/(\epsilon u)^{1/2}$ .

The magnitudes for the variables used here are: 700 nm red light has a ratio  $E/h = 4.2 \times 10^{14} \text{ s}^{-1}$  and thus an electric field dependence on time given by  $E(t) = (1.77 \times 10^{-4}) \sin[(4.2 \times 10^{14})t]$  or  $1.77 \sin(0.42t)$  with  $t$  in *femtoseconds* and  $E$  in  $V/m \times 10^4$ . The ratio  $E/\epsilon = 2.8 \times 10^{-19} \text{ J}/8.85 \times 10^{-12} \text{ C}^2/(N-m^2) = 3.16 \times 10^{-8} \text{ NVm/C}^2$ . The multiple  $Eu = (2.89 \times 10^{-19} \text{ J})(1.26 \times 10^{-6} \text{ T-m/A}) = 3.64 \times 10^{-25} \text{ TV/A}$  so the equation describing the magnetic field as a function of time is  $B(t) = 6.03 \times 10^{-13} \sin[(4.2 \times 10^{14})t]$  or  $0.603 \sin(0.42t)$  with  $t$  in *femtoseconds* and  $B$  in  $Tesla \times 10^{12}$ , or *picoTesla*.

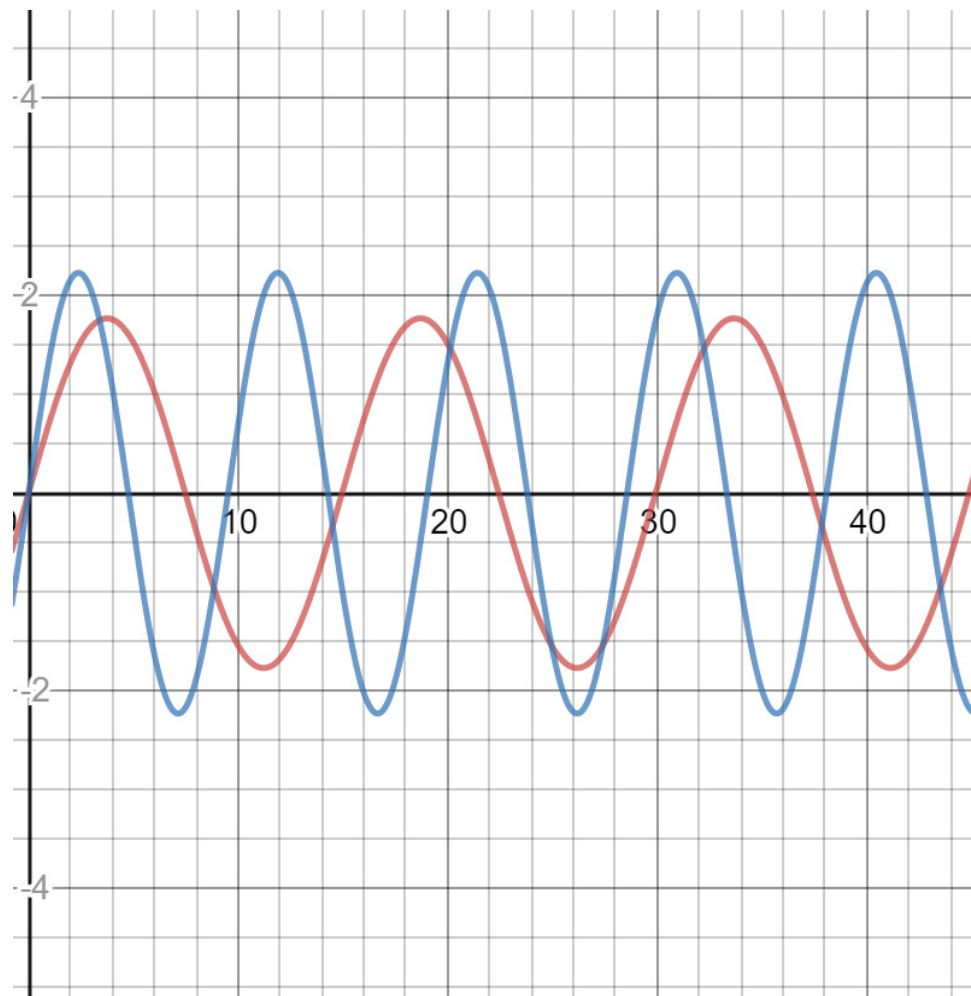
For 450 nm blue light,  $E/h = 6.6 \times 10^{14} \text{ s}^{-1}$ ,  $E/\epsilon = 4.4 \times 10^{-19}/8.85 \times 10^{-12} = 4.97 \times 10^{-8} \text{ J-A/(T-m)}$  so  $E(t) = (2.23 \times 10^{-4}) \sin[(6.6 \times 10^{14})t]$  or  $2.23 \sin(0.66t)$  with  $t$  in *fs* and  $E$  in  $v/m \times 10^4$ .  $Eu = 4.4 \times 10^{-19} \text{ J})(1.26 \times 10^{-6} \text{ Tm/A}) = 5.54 \times 10^{-25} \text{ TV/A}$  so  $B(t) = 7.44 \times 10^{-13} \sin[(6.6 \times 10^{14})t]$  or  $0.744 \sin(0.66t)$  with  $t$  in *femtoseconds* and  $B$  in  $Tesla \times 10^{12}$ , or *picoTesla*. The fact that light speed may be computed from either  $1/(\epsilon u)^{1/2}$  or from  $E/B$  may be shown by interconverting these formula. The magnitude of energy in light is equally divided between the electric field energy and the magnetic field energy where  $(1/2)\epsilon E^2 = (1/2)B^2/u$ . Substituting  $c^2$  for  $1/(\epsilon u)$  and rearranging produces  $E = cB$  and  $c = E/B$ .

## Results and Discussion

With our initial constraints in place, between time  $t = 0$  and time  $t = 7 \times 10^{-15}$  seconds, photons of 700 nm red light in air or vacuum trace three sinusoidal waves that span a distance of  $\sim 2100 \text{ nm}$  at a speed of  $\sim 3 \times 10^8 \text{ m/s}$ . Graphs of the electric field amplitudes a function of travel time for red and blue light are shown in Figure 1. Graphs of the magnetic field amplitudes for red and blue light are shown in Figure 2.

A similar graph may be made for the magnetic field amplitudes of photon tracings as a function of time. For simplicity, although the magnetic field is always orthogonal to the electric field, with maxima at the same propagation position, for simplicity the  $B$  field is also plotted along the vertical axis. Here the function would be  $B(t) = B_o \sin(ft)$ . Where  $B_o = (Eu)^{1/2}$ .

The presented pictures indicate the field amplitudes as a function of time. The expressions are also functions of distance since the lengths of each

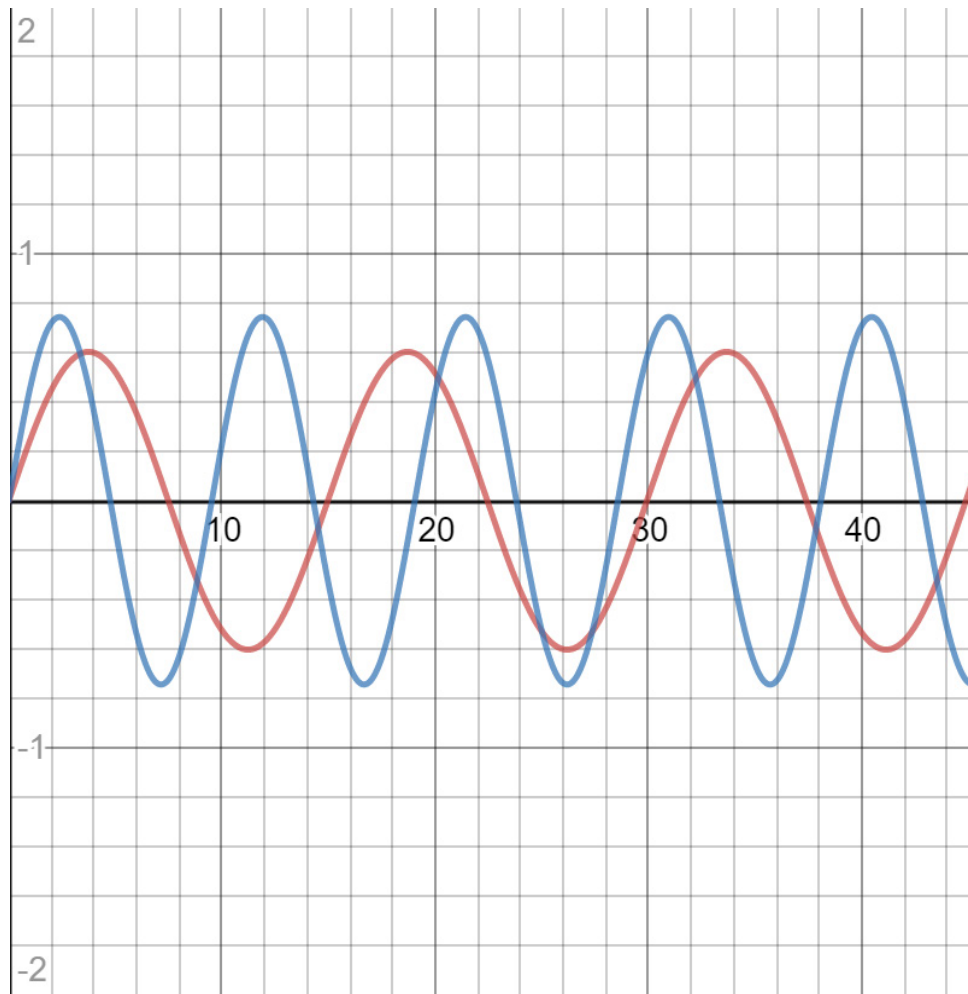


**Figure 1:** Tracings of the electric field generated by photons, traveling at speed  $c = 3 \times 10^8 \text{ m/s}$ , plotted as electric field amplitude ( $\text{V/m} \times 10^4$ ) as a function of time in *femtoseconds*. The function photons follow is given by  $E(t) = E_0 \sin(ft)$ . Here  $f$  is the frequency of the light, and the maximum amplitude of the electric field is given by  $E_0 = (E/\epsilon)^{1/2}$ , where  $E$  is the energy of the light. The distance traveled for blue light is  $450 \text{ nm}$  per wavelength. The distance traveled for red light is  $700 \text{ nm}$  per wavelength. The electric field maximum amplitudes are  $2.23$  and  $1.77 \times 10^{-4} \text{ V/m}$  for blue and red light. A time of  $9.5 \text{ fs}$  is required for each blue wave tracing to occur, and  $15 \text{ fs}$  is required for each red wave tracing.

wavelength are known in *nm*. The wavelengths are thus magnified approximately 2.5 million times actual size. Although the spatial distance over which the electric and magnetic fields emanate from the propagation axis is not known, it cannot be zero; it is finite. This is because electric and magnetic fields are vector quantities. A vector cannot exist at a single point (on the axis of propagation) but requires a finite domain of space. One may estimate that this space might be on the order of *nm* since the wavelength is in the *nm* range. For example, diffraction gratings that diffract visible light wavelengths are typically in the  $1,000 \text{ nm}$  slit width range [1], comparable to the wavelengths of visible light. Although the photon packet of EM energy is thought to be extremely miniscule, these graphs

may nevertheless present reasonable pictures of the actual spatial patterns of electric and magnetic fields formed by red and blue photons of light that propagate forward. During one wavelength of travel a blue  $400 \text{ nm}$  photon in air would rapidly pass 1,000 nitrogen molecules if lined end to end, each with a known diameter of  $\sim 0.4 \text{ nm}$ .

The integral of the functions over the time interval for a half wave produces an estimate of the field density spanning this spatial region. Indeed, the equations may be converted into field amplitudes as functions of distance rather than time, where  $d = ct$ , so that an integral unit would be in units of  $(\text{V/m})(\text{m}) = \text{Volts}$ . Knowing that a field must exist in a region of space, and the range of that space

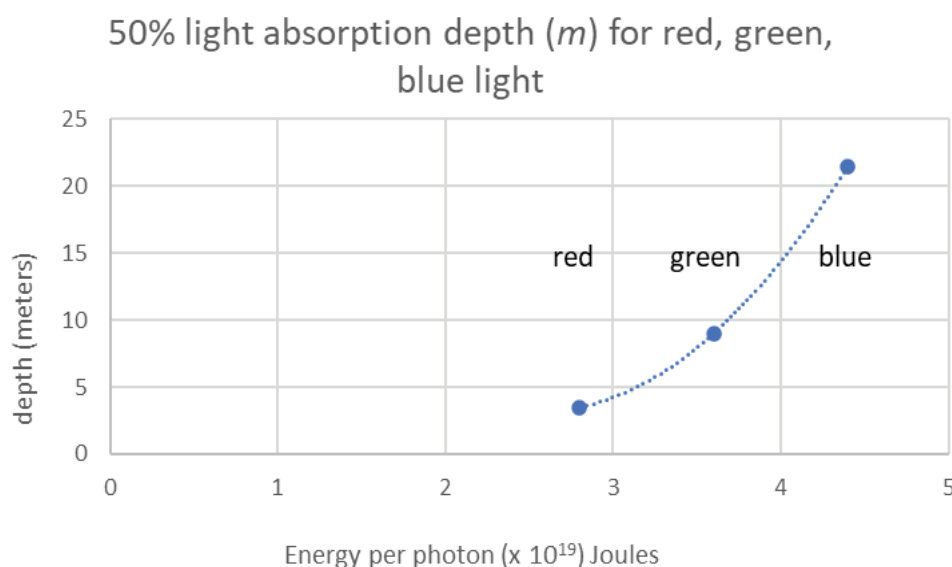


**Figure 2:** Tracings of the magnetic field generated by photons, traveling at speed  $c = 3 \times 10^8 \text{ m/s}$ , plotted as magnetic field amplitude (*picoTesla*) as a function of time in *femtoseconds*. The function photons follow is given by  $B(t) = B_0 \sin ft$ . Here  $f$  is the frequency of the light, and the maximum amplitude of the magnetic field is given by  $B_0 = (Eu)^{1/2}$ , where  $E$  is the energy of the light. The distance traveled for blue light is  $450 \text{ nm}$  per wavelength. The distance traveled for red light is  $700 \text{ nm}$  per wavelength. The magnetic field maximum amplitudes are  $0.744 \text{ pT}$  for blue and  $0.603 \text{ pT}$  red light. A time of  $9.5 \text{ fs}$  is required for each blue wave tracing to occur, and  $15 \text{ fs}$  is required for each red wave tracing.

must be a function of the magnitude of the field, it is possible to comment on the ability of the fields to interact with the medium through which it propagates. Blue light at  $450 \text{ nm}$  has 1.57 times the energy of  $700 \text{ nm}$  red light, but the integral of the half wave region indicates that the voltage perturbs the medium at a rate that is 2.12 times greater than for the red light. As seen in Figure 1 and Figure 2, the areas traced out by the fields for a blue photon half-wave occur at a time when the red photon fields have traced out a much smaller fraction of space.

Blue light with a larger electric field amplitude might cause the presence of a significant field over a distance that is less miniscule than that for red

light. This could be involved in determining the depth of penetration of light through translucent media and the greater refraction of blue light upon entering a chemical medium than that for red. Blue light forms the lower band of a rainbow with greater curvature than the red band, and blue light causes a larger refractive index in glass prisms than red does. The penetration of visible light into water for red, green and blue follows this order of depth (Figure 3) as described by a University of Hawaii study [6]. Infrared though is absorbed well due to matching the frequencies of atomic bond vibrations, and ultraviolet is absorbed well by aromatic  $\pi$  bonds in dissolved carbon dioxide, oxygen, and nitrogen gases. This trend however does not appear to hold in glass, so very different parameters are involved.



**Figure 3:** The depth in *meters* at which light intensity is reduced by 50% in fresh water is shown for red light, green light, and blue light as a function of energy content of the light (*Joules*  $\times 10^{19}$ ). In glass the relative absorption or penetration depth is opposite that here for water. Depth of penetration was obtained from reference [6].

The moving electric and magnetic fields in photons are unique. Electric charges produce electric fields, and magnetic dipoles produce magnetic fields around them. But these fields in light oscillate indefinitely even though there is no charge or magnetic dipole present to continue causing it. The electric and magnetic fields oscillate in time in a plane with nodes of absence at instants in time between fields of opposite direction. Like all fields, these follow the inverse square law, where the amplitude is proportional to the square of the inverse of the distance from the field source but differ from fields surrounding charges and dipoles that emanate in spherical space.

The fields in light have nodes of absence at the beginning, middle, and end of a wave tracing. The distance over which the field is significant between these nodal positions is not actually known. At nodes of wave tracings, photons exhibit no electric or magnetic fields. These fields are therefore regularly absent in repeating instants in time, but since the fields re-induce each other instants later, the EM energy exists at all times while the fields are oscillating from zero, to maximum amplitude, to zero, to minimum amplitude, to zero as a function of time. The EM spectrum covers a vast domain of energies. Long radio waves produce three nodes over a distance of 5,000 *km* in time 0.017 seconds, while typical gamma rays produce three nodes over

a distance of 3 *pm* in time  $10^{-20}$  seconds.

The average amplitude of the electric field for sunlight has been calculated based on the known solar radiation energy rate arriving on earth's surface ( $1350 \text{ W/m}^2$ ) at  $E = 1,000 \text{ V/m}$  [1]. As light speeds forward at speed  $c$ , electrons near this field would experience a force of  $F = Eq = 1,000 \text{ (V/m)}$  ( $1.6 \times 10^{-19} \text{ C}$ ) =  $1.6 \times 10^{-16} \text{ N}$ . Since electrons have a miniscule mass of  $9.3 \times 10^{-31} \text{ kg}$ , this relatively small electric force could cause a significant acceleration or jostling of nearby electrons in atomic or molecular orbitals, with some associated with absorption of photons. Undoubtedly the electric field interacts with matter at least at very close range. The extent of the interaction is likely related to the selective absorption of light photons traveling through transparent media.

### Photon Dimensions

The term photon was used to define the minimal functioning unit of light [7]. One viewpoint is that a single photon is an actual single wavelength of light, which oscillates while propagating forward. This leads to the notion that photons vary in size from miniscule for gamma rays to thousands of *km* in size for radio waves. However radio signals are readily received by detectors from close distances to source towers, far less than the length of a wave, without loss of information. This suggests



that a single photon is small and traces out a wave pattern, rather than only existing as an entity having the length of the wave it traces. A long radio wave leaves a tower as a functioning unit which happens to require a long distance of travel for fast light to propagate to complete a full wave trace, while the photon maintains its intrinsic frequency at all times. Further, how would a massive 5,000 km (3,125 mile) length photon diffract through narrow slits or reflect at an angle equal to the angle of incidence, or perfectly follow the inverse square law from its point of origin? The best explanation is that a photon is a functioning energy packet that oscillates while propagating forward to trace wave patterns. This is analogous to electrons tracing out wave patterns in atomic orbital clouds, while being point masses and not waves themselves.

Light not reaching the eye directly is invisible, in part because of the miniscule size of the photons that light contains, and in part because photons have no mass and thus do not reflect other sources of light. This is a property of light that is distinct from the well-known fact that light outside the visible spectrum cannot be seen even if that light does reach the eye. If one could travel alongside a single photon what size would it be while continuing to emanate its vibrating electromagnetic fields in wave patterns? Light passes through diffraction gratings with a slit width of 0.1 *microns* (100 nm), so photons are smaller than this, which compares to the size of viruses. Electrons also exhibit diffraction and have electric fields that may be compared in magnitude to that in light photons. Indeed, all light observed appears to be formed from the acceleration and de-energization of electrons, whether from stars, wired light bulbs, or excited gases, etc.

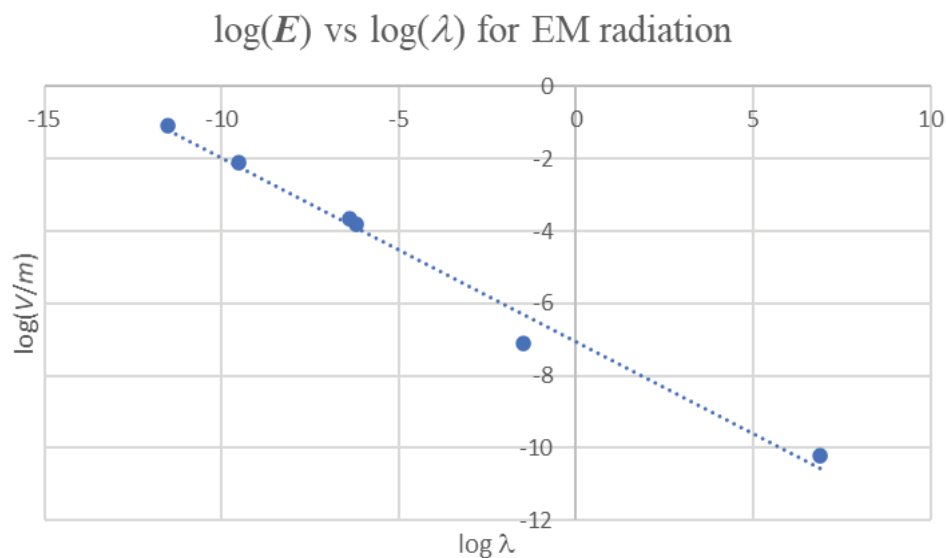
Could a functional photon compare in size to an electron that contains an electric field comparable to certain wavelengths of light? Again, electrons themselves are much smaller than the wavelengths they trace, and this is similar to massless photons that trace out wave patterns where the size of a functioning photon is much smaller than the wavelengths they trace.

Linus Pauling estimated the diameter of an electron at  $5.6 \times 10^{-15} \text{ m}$  [8]. Since the mass of an electron is 1,000 times smaller than the mass of a proton, and the proton diameter is known at  $8.3 \times 10^{-13} \text{ m}$ , assuming each particle is spherical with a

volume of  $(4/3)\pi r^3$  of similar density matter, then the ratio of the radii of these particles would be estimated from  $r_p^3/r_e^3 = 1,000$ , and the diameter of the electron  $2r_e$  would be  $3.4 \times 10^{-14} \text{ m}$ . Although there is no general agreement on the accurate size of an electron, this is in reasonable agreement with the Pauling estimate, and both compare to wavelengths computed from energies known to be observed for very high frequency gamma rays ( $\sim 3 \times 10^{-16} \text{ m}$ ). The miniscule possible physical size of a single functional photon corpuscle is of course uncertain.

The wavelength of long radio waves are of relatively low energy and thus low amplitudes of electric and magnetic field strengths. If one could freeze a photon in space at a position where its field amplitude is maximum, the field in theory would emanate through a significant distance. Tracings for a 60 Hz radio wave with energy  $4 \times 10^{-32} \text{ J}$  per photon and wavelength of 5,000 km, and a  $10^{20}$  Hz gamma wave with energy  $7 \times 10^{-14} \text{ J}$  per photon and wavelength of  $3 \times 10^{-12} \text{ m}$  would have electric field amplitudes ranging extremely widely from  $6.7 \times 10^{-11} \text{ V/m}$  to  $8.6 \times 10^{-2} \text{ V/m}$ . Microwaves with a frequency of  $10^{10} \text{ Hz}$  at  $6.6 \times 10^{-24} \text{ J}$  per photon and a 0.03 m wavelength, and X-rays with a frequency of  $10^{18} \text{ Hz}$  at  $6.6 \times 10^{-16} \text{ J}$  per photon and a  $3 \times 10^{-10} \text{ m}$  wavelength would have maximum electric field amplitudes of  $8.6 \times 10^{-8} \text{ V/m}$  and  $8.6 \times 10^{-3} \text{ V/m}$ . Figure 4 is a plot of the relationship between the logarithm of the maximum electric field amplitude as a function of the logarithm of the wavelength for various types of EM radiation.

There is additional evidence that a photon corpuscle of energy might be smaller in size than that of subatomic particles. Electrons or protons with a charge of  $1.6 \times 10^{-19} \text{ C}$  produce an electric field amplitude at 129 *um* equal to the maximum electric field amplitude of a gamma ray photon with 3 pm wavelength (from  $r^2 = kq/E$ ;  $r = [(9 \times 10^9 \text{ N-m}^2/\text{C}^2)(1.6 \times 10^{-19} \text{ C})/8.6 \times 10^{-2} \text{ V/m}]]$ ). The higher the wave frequency and energy, the higher is the electric field amplitude for light, and the smaller the wavelength and thus the limit on the size of an individual photon. This is not unexpected, where the electron has 7,000 times less volume than the proton but yet has just as large a charge and electric field amplitude. Miniscule wavelengths for known gamma rays have functioning photons and wavelengths that are correspondingly small, and yet the electric fields in the light may be duplicated by oscillating



**Figure 4:** The computed maximum amplitude of the electric field for waves traced by EM radiation varies as a function of the energy and thus the wavelength of the radiation. Plotted here is the logarithm of the electric field  $E$  (V/m) as a function of the logarithm of the wavelength (m). From left to right are results for gamma rays, X-rays, blue visible light, red visible light, microwaves, and radio waves. A log scale is necessary since wavelengths vary from 3  $\mu\text{m}$  for gamma to 5,000  $\text{km}$  for radio waves.

physical charges comparable to that of a single electron or proton. Low frequency light in the EM spectrum has lower  $E$  field amplitudes and would be duplicated by either smaller charges than single electrons or at greater distance from an electron.

Photons always reflect at an angle exactly equal to the incident angle which suggests a uniform spherical shape. It is possible that a single photon may have a physical size less or comparable to an electron at  $10^{-15} \text{ m}$ , while the electric field amplitudes oscillate over finite distances as the photon propagates through space. Indeed, the photon can be no larger in size than its own wavelength tracing. And notice that the smallest wavelength for gamma rays is on the order of  $3 \times 10^{-14} \text{ m}$ , at 30 times larger than the estimated diameter of a single electron which may be a more accurate estimate of the size of a functioning individual photon of light.

It is instructive to estimate the packing density, both linear and per volume, for photons in a sample of light. In principle the packing density can vary over a wide range depending on its intensity. However, photons are not likely to be tightly at  $10^{-15} \text{ m}$  apart, since sources emit light because of electronic transitions, where electrons sharing the same negative charge are unable to pack this closely and require finite times to de-energize and re-energize.

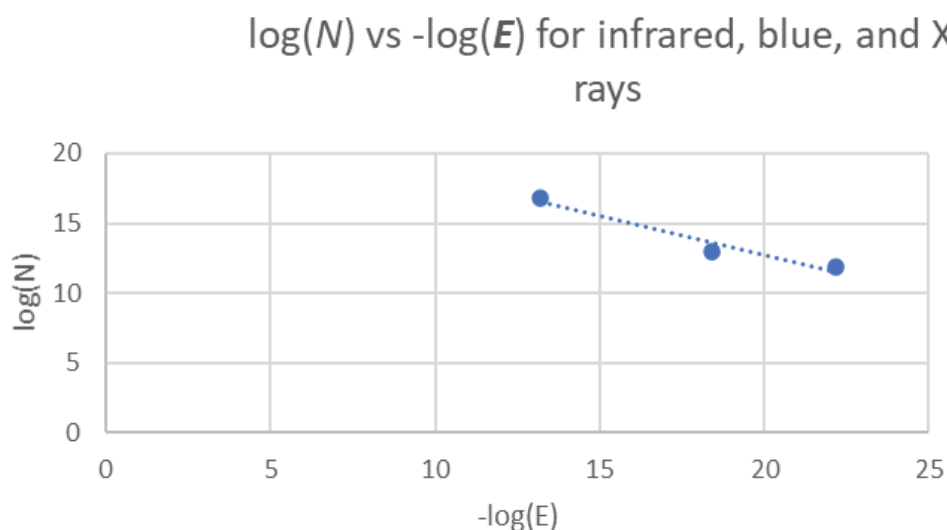
The number of photons per square meter in a sample of sunlight arriving on earth may be estimated from the known wattage that strikes the earth on average at full exposure, about  $1350 \text{ J}/(\text{s}\cdot\text{m}^2)$  [1]. Sunlight ranges from infrared to X-ray in wavelength. If this were all blue light, this would amount to  $3.07 \times 10^{21}$ , or  $5 \times 10^{-3}$  Einsteins or moles of photons per *second per meter squared*. Since photons travel 1 *meter* in 3.3 *ns*, then a cubic meter of volume would contain  $1 \times 10^{13}$  photons that reach earth from the sun each 3.3 *ns*. Assuming uniform distribution of photons in this volume, this amounts to a photon occupation space of  $10^{-13} \text{ m}^3$ . A 1 *meter* length is  $1/450 \text{ nm} = 2.2 \times 10^6$  wavelengths of blue light, so this suggests an array of photons in the square meter would contain  $4.5 \times 10^6$  rays separated by an average 0.22 microns, about the size of a few virus particles. This seems quite large, since sunlight can be diffracted through slits less than this diameter, but light travels so fast that in one *millisecond*  $3 \times 10^{18}$  photons pass a single location, all spread throughout the *square meter* area. Sunlight is formed from energy transitions by electrons in a massive dense plasma, from all minute locations in an array. At  $1.5 \times 10^{11} \text{ km}$  from the source, the dilution of the density of light rays following the inverse square law suggests a photon density of  $6.9 \times 10^{43}$  photons per cubic meter ( $3.07 \times 10^{21}$  photons  $\times$

$1.5 \times 10^{11} \text{ km}^2$  at the sun surface. Interestingly, this is an average occupation volume of  $1.4 \times 10^{-44} \text{ m}^3$  per photon, and the cube root of this volume gives an estimated photon separation distance of  $2.4 \times 10^{-15} \text{ m}$ , which is indeed an estimated diameter of an electron. The longest wavelength theoretically possible would be a photon with frequency 1 oscillation per second with energy  $E = hf = 6.6 \times 10^{-34} \text{ J}$  and wavelength  $\lambda = c/f = 3 \times 10^8 \text{ meters}$ .

These calculations are of course crude but do suggest that after traveling 93 million miles from sun to earth that photon density is significantly expanded, as expected. Electrons in normal matter are known to approach no closer than about the diameter of a hydrogen molecule, at  $289 \times 10^{-12} \text{ m}$ . So the volume of space surrounding electrons in matter, and the limiting minimum volume of space surrounding a photon if the source were emissions from energized hydrogen gas, would be estimated at  $(4/3)\pi r^3 = 1.3 \times 10^{-29} \text{ m}^3$ , the volume of a single molecule of hydrogen. Any sample of light may vary in intensity with a range of photon occupation volumes. Sunlight must indeed be produced by a plasma of densely packed electrons rather than from energized hydrogen molecules. If all sunlight energy arriving on earth at  $1350 \text{ J/(s-m}^2\text{)}$  were  $30 \text{ nm}$  X-rays, the volume per photon would be  $1.4 \times 10^{-12} \text{ m}^3$  and if  $3 \text{ mm}$  infrared light the volume would be  $1.5 \times 10^{-17} \text{ m}^3$ . A plot of the logarithm of the number of photons  $N$  contained in a  $1 \text{ m}^3$  volume with  $1 \text{ m}^2$  cross section is shown for the sunlight spectrum

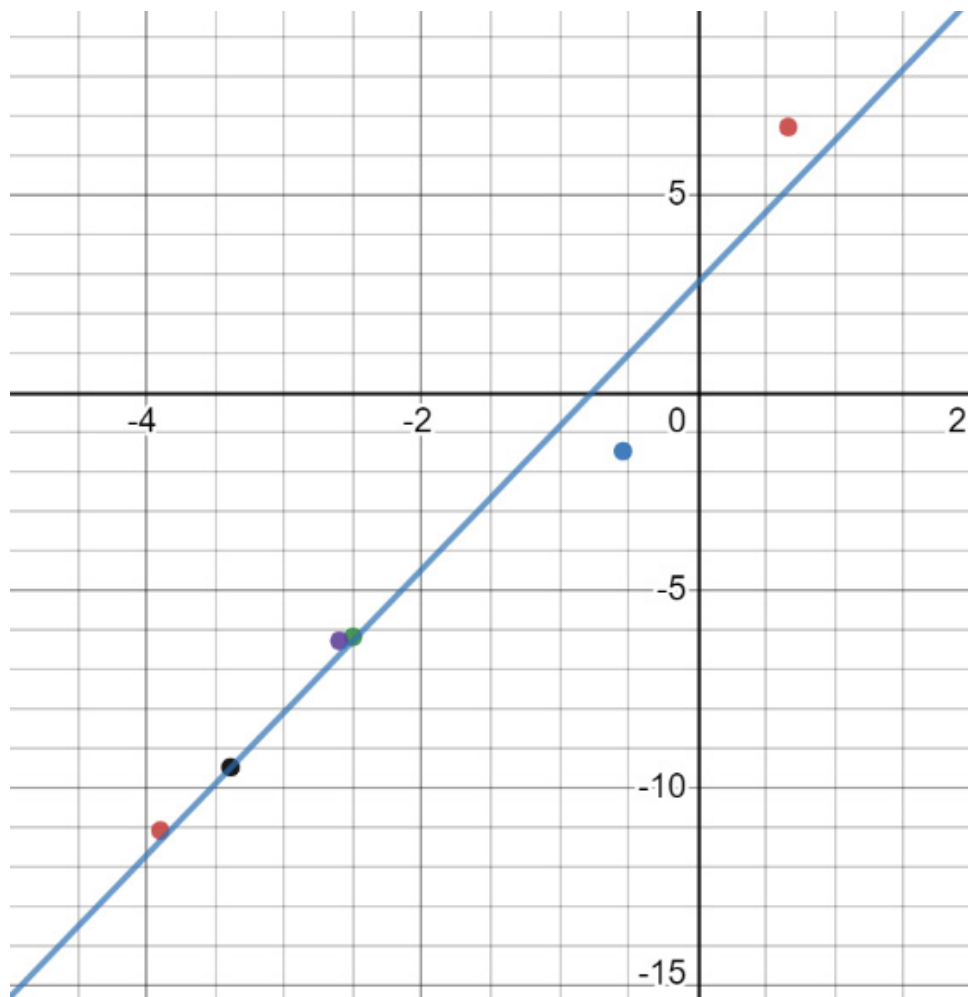
from infrared at  $6.7 \times 10^{16}$ , to blue light at  $1 \times 10^{13}$ , and X-rays at  $7.1 \times 10^{11}$  photons/ $\text{m}^3$  (Figure 5A) all samples having equal energy rate of  $1350 \text{ J/(s-m}^2\text{)}$ . As the photon energy  $E$  increases, the number of photons that would exist in one *cubic meter* in an equal energy sample of course decreases. The volume per photon therefore is  $1/N$  and therefore the negative  $\log(N)$ . This means the volume of space occupied per photon increases as the energy per photon increases from  $1.5 \times 10^{-17}$  to  $1 \times 10^{-13}$  to  $1.4 \times 10^{-12} \text{ m}^3$ . Blue light with a wavelength of  $450 \text{ nm}$  ( $2.2 \times 10^6$  wave tracings per *meter*) and frequency  $\text{Hz}$  at  $1350 \text{ J/s-m}^2$  contains  $10^{13}$  photons per  $\text{m}^3$ . This suggests there are photon rays that span a line across a *square meter* of space with a separation distance of  $220 \text{ nm}$  ( $10^{13}/2.2 \times 10^6$ ).

At this point it must be stated the difference between natural and artificial EM radiation. Light from stars and our sun consists of a wide range of wavelengths, the sun from low infrared to high ultraviolet, and according to NASA photographs the Milky Way of stars emits wavelengths from radio waves to gamma rays. All these forms are produced from electrons that undergo transitions to lower energy states in a plasma of high energy electrons at star surfaces. Microwaves generated in klystron tubes artificially produce wavelengths that compare with low infrared, and X-rays produced artificially be electron deceleration have wavelengths that compare with the higher ultraviolet. So it is more accurate to state that stars and our sun naturally



**Figure 5A:** The log of  $N$ , the number of photons in one *cubic meter* of light containing an energy rate of  $1350 \text{ J/(s-m}^2\text{)}$  is plotted as a function of  $-\log(E)$ , the photon energy for infrared light (left), blue light, and X-rays (right).





**Figure 5B:** The logarithm of the distance  $r$  in *meters* at which an electron produces an  $E$  field equal to the maximum  $E$  (vertical axis) for various types of EM radiation are plotted as a function of the logarithm of the wavelength in *meters* (horizontal axis). From left to right, as the wavelength decreases for radiowaves ( $5 \times 10^6$  m), microwaves ( $0.03$  m), red light ( $7 \times 10^{-7}$  m), blue light ( $4.5 \times 10^{-7}$  m), X-rays ( $3 \times 10^{-10}$  m), and gamma rays ( $2 \times 10^{-12}$  m), the distance from an electron that produces a corresponding  $E$  field amplitude also decreases (with values of  $4.6$  m,  $0.129$  m,  $0.00285$  m,  $0.00256$  m,  $0.0004$  m, and  $0.000126$  m). The relation is linear and follows  $\log r = 3.62(\log \lambda) + 2.75$  where  $r$  and  $\lambda$  are in *meters*.

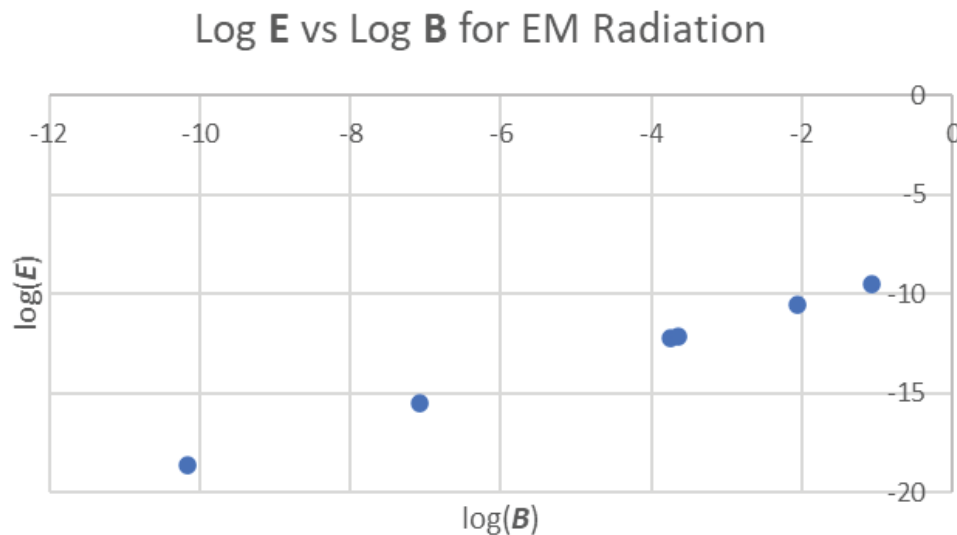
produce radiation that may be mimicked artificially. Gammas rays are not in sunlight but are also naturally produced from lightning and from various radioactive substances.

Although electrons and photons undergo diffraction through thin slits, electrons have mass and do not have a fixed intrinsic speed. Photons have no mass and propagate at fixed intrinsic speed and do not generate friction even in non-vacuum media. Electrons in atoms travel in orbital clouds in wave patterns, continuously changing speed and distance from the nucleus due to the electric force between protons and electrons coupled with the rapid lateral velocity of the electron. Photons

however do not travel in a wave pattern but rather travel in straight trajectories at fixed speeds while the electric and magnetic field amplitudes produce a wave pattern in space. Figure 5B presents the relative distance from an electron at which its electric field  $E$  would equal the maximum amplitude  $E$  for various types of EM radiation.

### Intrinsic Photon Speed

Photons are unique in having no charge and thus no attraction to negative or positive charges, and yet having oscillating electric fields similar to fields surrounding alternating currents of electrons. Photons must travel at rapid speed  $c$  in order to exist while these fields fluctuate and induce and annih-



**Figure 6A:** The relation between the logarithm of the maximum electric field amplitude  $E$  vs. the logarithm of the maximum magnetic field amplitude  $B$  is plotted for EM radiation of energies typical for radio waves, microwaves, red and blue light, X-rays, and gamma rays. The average value of  $\log[E] - \log[B]$  for all EM radiation is approximately 8.48. Since  $\log[c] = \log[E/B] = \log[E] - \log[B]$ , then  $c = 10^{8.48} = \sim 3 \times 10^8 \text{ m/s}$  for photon radiation of all energies over the entire EM spectrum.

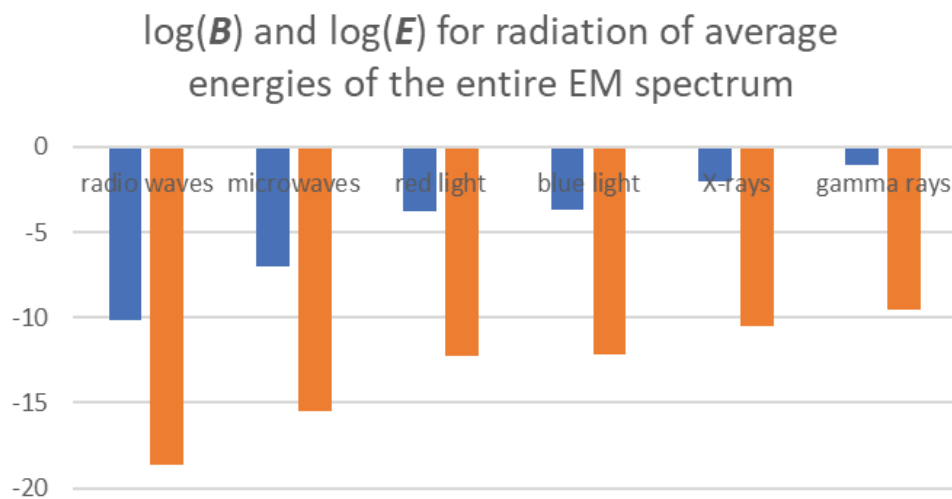
late each other rhythmically in unison, while fields around electrons and protons are static and would vary at a single position in space only as an electron passes by. Long wavelength low energy radio waves consist of photons as do high energy gamma rays. The idea that the photon packets might be larger for the more energetic gamma rays is not likely, since the forward propagation speed of all photons over the vast range of different energies is exactly the same for all in a given medium, speed  $c$ . This strongly suggests that the difference is not photon size but energy density for the broad array of wavelengths of EM radiation. The higher energy oscillates with a larger amplitude for the electric and magnetic fields and at greater fluctuation frequency than for low energy radiation, all propagating forward at identical speeds since speed is the ratio of the two field amplitudes,  $c = E/B$ . Radio waves and gamma rays in vacuum have the same ratio,  $c = (6.7 \times 10^{-11} \text{ V/m}) / (2.2 \times 10^{-19} \text{ T}) = (3.4 \times 10^{15} \text{ V/m}) / (1.14 \times 10^7 \text{ T})$ , respectively. Note that units for  $(\text{V/m})/T$  simplify to  $\text{m/s}$  since units for  $V$  are  $(\text{kg} \cdot \text{m}^2) / (\text{C} \cdot \text{s}^2)$  and for  $T$  are  $\text{kg} / (\text{C} \cdot \text{s})$ .

Figure 6A depicts the relation between photon energy (from  $E = hf$  Joules) as a function of reciprocal wavelength ( $1/\lambda \text{ m}^{-1}$ ) for EM radiation spanning in frequency from radio waves to gamma rays. The relation is as expected linear, with a slope given by

$hc$ . Dividing the observed slope by Planck's constant  $h$  computes the intrinsic speed  $c$  at which all EM radiation travels. When graphed directly as in Figure 6B, the difference between  $\log(E)$  and  $\log(B)$  appear to remain constant for all radiation over the entire EM spectrum of energies. This demonstrates that all EM radiation propagates forward at intrinsic speed  $c$  regardless of the intrinsic energy that it contains, where gamma ray photons typically contain  $1 \times 10^{18}$  times more energy than radio wave photons. Here  $\log(E) - \log(B) = \log(E/B) = 8.48$  and thus  $c = 10^{8.48} = \sim 3 \times 10^8 \text{ m/s}$ .

### Plane Polarized Light

The electric field oscillations of EM waves can induce alternating currents in electron-rich metallic antenna. Unpolarized photons of light in nature rotate rightward or leftward, while plane polarized light can be rotated by chiral compounds in solution, and birefringent materials selectively absorb light to produce circularly polarized photons. Plane polarized light rays contain photons that synchronously rotate in opposite direction around the propagation axis. When interacting with birefringent matter, one of the rotating direction rays is absorbed producing circularly polarized light. Such light is recognized in nature by creatures such as ants for apparently navigation purposes. Plane polarized light is rotated to a different orientation



**Figure 6B:** The log of the maximum  $E$  (left bars) and the log of the maximum  $B$  values (right bars) are graphed for light over the entire EM spectrum. Both quantities increase as the energy increases for light frequencies from radio waves to microwave to red light, blue light, X-rays, and gamma rays (from left to right). Note the difference between the two values appears identical for all frequencies of light. Here the difference is  $\log E - \log B = \log(E/B) = 8.48$ , and thus  $\log c = 8.48$  and  $c = 10^{8.48} = \sim 3 \times 10^8 \text{ m/s}$  which is the intrinsic speed of all forms of EM radiation regardless of energy content.

by chiral chemicals through which light passes. Although it has been thought to be due to refraction or birefringence this is not the case because the reoriented light remains plane polarized and may thus be due to the Faraday effect discovered by Maxwell in the late 19<sup>th</sup> Century, where magnetic fields through which polarized light passes can rotate the orientation plane.

### Light and Mass Energy Transformations

Electrons in atomic orbitals have light-like properties traveling rapidly in wave patterns where the wavelength of an electron in the ground state 1s orbital of hydrogen is the circumference of the hydrogen atom ( $3.1 \times 10^{-10} \text{ m} = 0.31 \text{ nm}$ ), 55,000 times the estimated electron diameter. Electrons have mass and are not photons of light. Light has no mass and is not an electron but exhibits particle-like properties such as light scattering, the photoelectric effect, and the generation of an electric field.

Light is generally produced by the energy transitions undergone by electrons in atoms, or in plasma such as on the surface of the sun. Thus the production of light, which itself has no mass, as expected does not involve loss of mass. The absorption of light at the surface of the earth and by green plants is likewise not associated with an increase in mass of the absorbing material. However, in theory en-

ergy transformations can occur where light energy could be converted into mass energy, following the well-known  $E = mc^2$ . But at the instant a photon is converted into mass, it is no longer light. Likewise when mass is annihilated into another form of energy, that mass energy is no longer a physical mass.

The statement that light has no “rest mass” is misleading because light is never at rest. For light to exist it must propagate at rapid intrinsic speed  $c$ . It is more accurate to state simply that light has no mass or mass energy. However, light energy can be theoretically converted into mass under certain circumstances, just as mass energy can be converted into light energy or other forms of energy as well. De-energized electrons that produce light emission do not lose mass. However, on the sun and stars where nuclear fusion reactions take place that continuously re-energize electron plasma, mass is lost, so that energy conservation remains. The mass is lost to provide electronic energy, but mass is not lost in the production of the released light itself. Although mass is lost in a nuclear explosion, whether by fission or fusion, on a net basis the lost  $mc^2$  energy appears as explosive energy plus heat energy plus light energy, while mass loss is not required for the production of light. Even though light exhibits properties that masses have, such as photoelectric effects, light is not mass, has no mass, and is the only entity that travels at light speed  $c$ . (For exam-

ple only light regains its speed  $c$  upon entering air from water or glass automatically due to the properties of air. Objects with physical mass have no such ability). As a corollary, mass is also not light, even though mass can exhibit wave and other light-like properties.

## Features Summary

Taken together, the data suggest that photons are uniform miniscule corpuscles [9] of light as proposed originally by Newton, but which are massless energy, with electric and magnetic oscillations that can compare with fields around charges. The size of a photon is finite but the functional oscillating unit must be limited by the thin slit width of diffraction gratings at  $100\text{ nm}$  but are likely very much smaller. The wavelength traced by a given photon is determined by its intrinsic energy and oscillating frequency. If the functional dimension of a photon is comparable for EM radiation generally, then the maximum amplitude of charge that would form an electric field at an assumed distance of  $100\text{ nm}$  could be computed from  $q = Er^2/k$ . Radio waves would compare to a point charge of  $q = 7.4 \times 10^{-35}\text{ C}$ , and a gamma ray would compare to a charge of  $q = 3.8 \times 10^{-26}\text{ C}$ . These small charges suggest that the size of a functional oscillating photon corpuscle of energy may be far smaller than the size of an electron. Photon energy however contains no mass or actual charge.

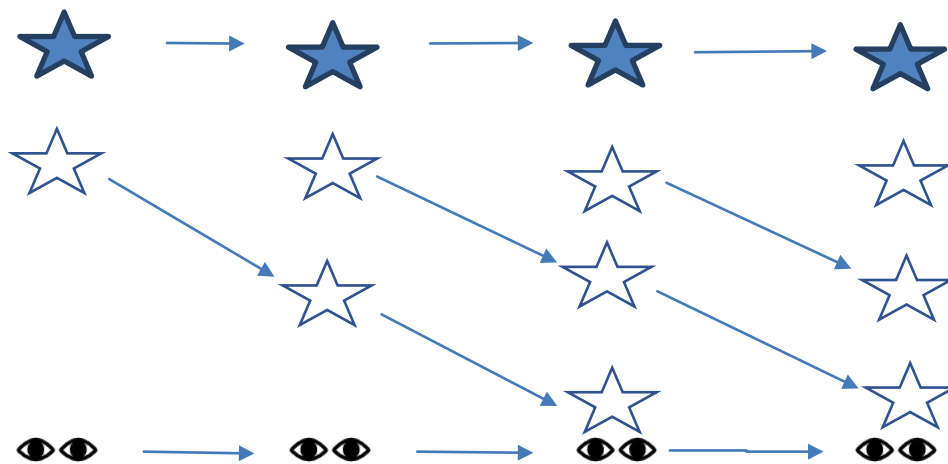
## Light Aberration

An aberration refers to the departure from normal, or from what is expected. For propagating light, there are two recognized forms of unexpected activity. Bradley aberration occurs when light sources are in motion with respect to stationary, or less mobile, detectors, such as rotating twin stars observed from earth. Light photons travel to the earth at a greater angle than from stars that are more relatively stationary. And secular aberration is due to motion of detectors from less mobile light sources, such as the detection on the moving earth of rays from stars that are more stationary than the lateral traveling earth between summer and winter that cause parallax due to the differing positions of the observed stars in the sky.

Surprisingly, a third, and most common, form of aberration exists for residents on earth, where light sources and detectors are both in uniform motion together. Due to the sun-orbiting, axis-spinning and

tilting, and rotation of the earth in the Milky Way galaxy, all objects on earth are in perpetual motion. Earlier studies demonstrated that light photons depart from lateral moving sources with the lateral speed of the source, while propagating at forward intrinsic speed  $c$  [4]. This explains why Bradley aberration occurs, but also is involved in what may be described as synchronous aberration. Rays of light from a moving source are composed of a line of photons that themselves travel at an angle from the particular coordinate in space at which each is produced, to a detector that shares the motion of the source. Thus the image of objects travels from the moving object to the moving detector in such a way as to constantly be directly between the object and the detector.

Synchronous aberration of light is described in Figure 7, which represents the images of an object produced at successive coordinate positions of an object, that angle travel toward the observer until being detected. Images of objects seen by observers on earth are always made at the position in space at which the light departed the object (as shown for the object filled star and image empty star on the left. This is different than the position the object is located at the time the image is detected and absorbed by the eyes at the third position. Since light speed is very rapid, the shift the object and detector make during the travel time of the light image on earth amounts to about  $3\text{ mm}$  of shift for a light travel distance of  $30\text{ meters}$ , considering the orbit speed of the earth at  $65,500\text{ miles per hour}$  ( $30\text{ km/s}$ ). Interestingly, the image remains between the object and the observer at all times while angle-traveling from source to observer. So all things seen on earth are images made from objects that were in a different location than when the objects are seen, and nevertheless are in position in front of the object during this light image travel time. The fourth position on the far right shows the image arriving at the eyes after having traveled from the object when it was at the second position. The images make a vertical ray of light at this rightward fourth position that actually is composed of photons that had been produced at the sequential second and third positions, while a new image is forming at the source now in the fourth position. The image that had been produced from the source at the initial position at left is not present at the fourth position because at this time the image has been absorbed by the eyes. This “space-



**Figure 7A:** Demonstration of synchronous aberration. The position of an object (filled star) and an observer (eyes) on earth shift as a function of time due to the orbital motion of the earth, as depicted from left to right at four representative locations viewed from above the ground. Any light reflected from, or produced by, the object (the empty stars) that is later absorbed by the eye must travel from the location of the source where and when it is first produced, along an angled trajectory, to the location at which the eyes are located at the time the image arrives. Successive images of the object are produced at each shifted position of the source, and all later arrive at corresponding shifted positions of the eyes. If the light images were photons from a laser beam in a cloud chamber, the light would appear as a ray traveling vertically from source to eye. The figure however demonstrates that the observed ray is actually composed of photons that angle travel from the source to the eye as both source and eye move laterally together. Note that the image of the object remains at all times directly between the source and the eye, as the source, eyes, and image all exhibit lateral motion. Light picks up the lateral velocity of lateral moving sources while propagating with intrinsic speed  $c$  from the location at which it departs the source. Those photons arriving at a shifting detector are absorbed after angle traveling at speed  $c$  along this trajectory while having a horizontal component of velocity equal to that of the source and detector. The time required to travel from the image to the eye is  $L/c$  where  $L$  is the length of the angled path traveled by each photon and is not the distance between source and the eyes.

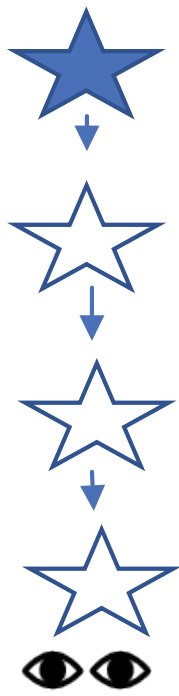
time" graph is analogous to the detailed diagrams of the shifted positions of stars presented by Otis [10].

The reason that the system described in Figure 7A is an aberration is because the light appears to form a vertical ray directly from source to eyes at any given position of the eyes, while in actuality this is a mirage. The actual travel path for the images is angled with a distance  $L$  that is longer than the simple linear distance  $D$  along the ground between the source and the eyes. The time required to travel from source to the eyes is  $L/c$ , where  $L$  is the actual path the light takes between its departure at the upper left to its arrival at the eyes at the lower right. Although an observer moving with the earth might presume the photons only traveled the linear distance along the ground between source and eyes  $D$  to compute time for the event as  $D/c$ , this is an error, as seen in Figure 7B. Reflected light appears as solid rays in a cloud chamber because

the photons travel so fast. And even though a source moves laterally, a finite time is necessary for a photon to be produced by that source. The time required to form a  $440 \text{ nm}$  blue photon is limited at no less than  $c/\lambda = \text{femtoseconds}$  since electrons with mass cannot exceed speed  $c$ .

Figure 7B demonstrates the light ray formed by images from the same source that travel to the eyes in the theoretical case if the earth could be made completely stationary. Here the vertical ray formed is not a mirage because this is the actual travel path for the photon images. The linear distance  $D$  along the ground is equal to the distance traveled by the photon images. The time required to reach the eyes is  $t = D/c$ . Thus there is no such thing as 'dilation of time due to motion'. Merely a longer time  $L/c$  is necessary for light to travel a longer distance than for a shorter distance. As reviewed earlier [4] the difference in time  $L/t$  versus  $D/t$  for the moving system in 7A is not simply an error made because





**Figure 7B:** The path taken by light images if the source and detector could be made to be completely stationary in space. Photons here form a linear ray with each having the same bearing pointing toward the earlier formed photon in ‘follow the leader’ style. The time for the image to propagate from source to the eyes would be  $t = D/c$  where  $D$  is the linear distance between source and target.  $t$  is here longer than time  $t$  for synchronous aberration due to motion shown in Figure 7A. The difference in magnitude of time is not due to dilation of time, but rather merely reflects the longer distance light must travel when the system is in motion.

the observer is moving laterally with the source and eyes. A distant observer on either side could also presume the distance traveled by the light is  $D$  even though this observer is not moving. Time dilation due to motion is unfortunately a long-standing error that has led to much false extrapolation.

### Definition of the Meter

Synchronous aberration affects the use of light to define the length of a *meter*. The procedure accuracy is limited by the orbital velocity of the earth, which varies between seasons. This is because the time required for light to pass a stationary one *meter* distance is not the same as the time to pass a one *meter* length that is orbiting in space with the earth. The earth moves laterally about 0.1 *mm* in the time light takes to travel one *meter*. Likewise,

if the light is oriented in the direction the earth travels, then the distance light travels is longer than one *meter* in the forward direction and less than one *meter* in the reverse direction. Although a round trip of travel reduces this synchronous aberration error, the problem is that the extra distance traveled along an absolute *meter* in the forward direction is not the same magnitude as the lesser distance traveled in the reverse direction. The forward distance is one *meter* +  $vt$  where  $v$  is the orbital velocity of the earth and  $t$  is the time required for light to pass the one *meter* plus the extra shifted distance. In the reverse direction, the light travels less than one *meter*, but not a distance that automatically cancels out the increased distance for the forward direction. This distance of travel is less than one *meter* by the distance the earth travels during the reverse time, which is not equally less than the forward time. The total travel time depends on the velocity of the earth. This has been fully addressed earlier [4,10].

A highly accurate and reliable International Standard Unit (S.I.) definition of the meter historically is that used since 1875, the solid *meter* iridium-platinum bar in Sevre, France equilibrated at 0 °C by the International Bureau of Weights and Measures. Other methods, the use of light wavelengths, the use of atomic clocks, or the original definition being 1 ten millionth of the distance from the North pole to the equator along the Parisian meridian (1793), are accurate because light speed is substantially faster than orbital velocities, but are all technically affected by natural geologic and motional variables.

### Light-Matter Interactions

No matter how intense light is, with a wavelength that does not match the frequency energy of the resonating electrons in chlorophyll, it is not absorbed. Only a matching frequency is absorbed and in this way compares to a physical photoelectric effect where a proper light frequency is necessary to energize electrons in wire. The difference is that higher frequencies do not remove chlorophyll electrons and thus this is referred to as a specific absorption. The use of the charge on an electron for Figure 5 is arbitrary and for instructional purpose. Photons of differing energy might produce fields with amplitudes that compare to the fields surrounding variable charge, rather than being a fixed charge.

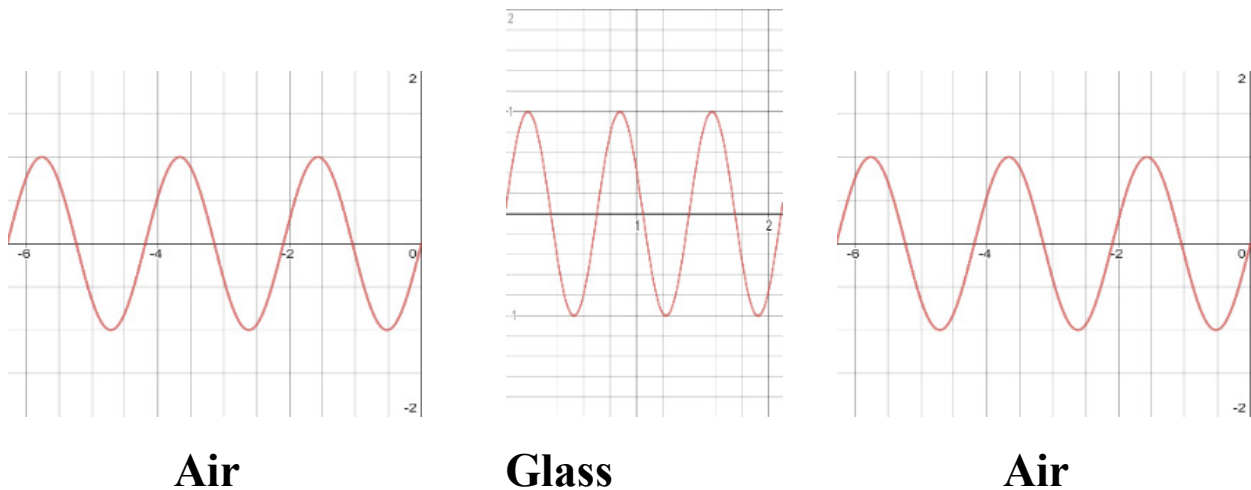
Other than frequency matched absorption events, light samples passing through translucent media eventually with enough time and distance diminishes to imperceptible. In water, infrared is absorbed due to matching frequencies with molecule bond vibrations and bending, and UV light is absorbed likely because of the content of nitrogen and oxygen with their  $\pi$  multiple bonds. But wavelengths in between infrared and UV are also eventually absorbed, with higher energy blue light traveling deeper into water than lower energy red light. In a light sample traveling through water, a small fraction of photons would be expected to pass directly through, or close to, material electrons. The force  $F$  and impulse  $I$  generated by the electric field on the electron could be roughly estimated from  $I = Ft = k(E_o/2)q\lambda/(2c)$ , where  $t = \lambda/(2c)$  for a half wavelength to pass,  $E_{ave} = E_o/2$ , and  $F = Eq$ . The impulse imparted for various wavelengths of the EM spectrum are computed using this formula  $I = E_o q \lambda / (4c)$  and was found to vary from  $4.5 \times 10^{-32}$  N-s for radio waves, to  $3.5 \times 10^{-37}$  N-s for microwaves to  $3.5 \times 10^{-41}$  N-s for gamma rays. The second half wavelength would exert an oppositely directed electric field, imparting an equal but opposite impulse. One possible explanation for light loss in transparent media then is that photons passing through or near material electrons experience energy loss or absorption because of this interaction until over time the light diminishes to non-detectable. The affected electrons would be vibrated or jostled, rather than given a net imparted velocity.

In the above analysis note that higher energy gamma rays exert potentially a smaller impulse, but this is because of the short time the half-wave passes, at  $t = 1 \times 10^{-20}$  seconds compared to the much longer time for a radio wave at  $t = 0.016$  s. During these times the total impulse imparted by the radiation is obtained by multiplying by the number of waves that pass. The total imparted impulse for a ray of radio waves would be  $6.8 \times 10^{-27}$  N-s and for gamma rays would be a million times larger at  $6.8 \times 10^{-21}$  N-s. In reality, an electron moving at sub-light speeds would be exposed for a very small time interval, where its average velocity in a 1s orbital in a hydrogen atom, from  $kqQ/r = mv^2$  would be  $v = \{9 \times 10^9 \text{ N-m}^2/\text{C}^2 (1.6 \times 10^{-19} \text{ C})^2 / [(5.3 \times 10^{-11} \text{ m})(9.3 \times 10^{-31} \text{ kg})]\}^{0.5} = 2.2 \times 10^6 \text{ m/s}$ . Thus this electron would travel 34,500 m in the radio half wave travel time but only  $2.2 \times 10^{-14}$  m in the respective time for a gamma half wave. An electron travels the di-

ameter of a hydrogen atom in about  $4.8 \times 10^{-17}$  s. In this time interval, all light travels 14 nm. Thus an efficient electron vibrating type of EM radiation interacting with matter would be expected to have wavelengths similar to the diameter of an atom or molecule, namely in the nm range of UV light. These considerations partly explain the tremendous difference in behavior of various types of EM radiation interacting with a given type of matter.

Light is homogeneous in that each finite volume contains photons with frequencies varying from low infrared to high ultraviolet. If a sample of blue light photons could be frozen in time and counted, one cubic micron of visible volume would contain  $1 \times 10^5$  photons at the above energy rate, a miniscule number compared to the number of molecules in this volume of air. In a 1 ms photograph,  $3 \times 10^{10}$  photons would pass through this volume, or 30 billion per cubic micron with each blink of an eye. Light with this intensity entering the eye through the pupil opening when directly gazing at the sun is sufficient to damage the rod and cone cells that absorb visible light to activate the optic nerve. Visualizing objects occurs safely because sunlight is reflected off surfaces after some is absorbed and scattered.

Figure 8 presents graphs of successive tracings by red light over a distance of three wavelengths in air, followed by tracings in glass, and then air again. The frequency of light is an intrinsic property that in all cases is determined by the energetics of the electronic accelerations at the source that produce the light. When light enters glass or another medium than air or vacuum, the light speed slows so at the fixed intrinsic frequency, the traced wavelength pattern is shortened. The original characteristics return again as light leaves glass and returns to the original medium. As previously discussed [4], objects with mass do not have this capability, and this demonstration confirms that light is EM radiation that has no mass. This also means that light is not subject to gravity which only attracts objects with mass. Hypotheses that black holes in space might have gravity that attracts light strongly backwards are not credible. In fact, black holes are not holes since if dense objects with gravity are present, and might be referred instead as black bodies. Why light does not travel from a black body to earth is not known, where light can simply be extinguished, blocked, absorbed, reflected, or refracted from a



**Figure 8:** Patterns traced out by the electric field for light photons that propagate for three waves of travel in air, then in glass (center), then back to air again. The wavelength and velocity correspondingly decrease in glass and air, while the frequency of the light is an intrinsic property that is fixed in both media. Here, in air the velocity is  $v_{\text{air}} = f\lambda = c (= 3 \times 10^8 \text{ m/s})$ , while in glass the velocity is  $v_{\text{glass}} = f\lambda' = c' (= 2 \times 10^8 \text{ m/s})$ . The speed of light in any medium other than vacuum is  $c' = c(\lambda'/\lambda)$  where  $\lambda' = \lambda/n$  and  $n$  is the refractive index of the medium.

path toward earth, or other reasons besides the notion that gravity is involved.

Between time  $t = 7 \times 10^{-15}$  seconds and  $14 \times 10^{-15}$  seconds a photon of red light traces three waves in a forward propagation distance of  $\sim 1400 \text{ nm}$  distance in silicate crown glass ( $n = 1.5$ ), traveling at  $\sim 2 \times 10^8 \text{ m/s}$  ( $n$  for violet light in this glass is 1.52). From time  $t = 14 \times 10^{-15}$  seconds to  $21 \times 10^{-15}$  seconds the photons trace three sinusoidal wave patterns over a distance of  $\sim 2100 \text{ nm}$  again in air or vacuum at a speed of  $\sim 3 \times 10^8 \text{ m/s}$ . All EM radiation regardless of frequency travels a distance of  $2100 \text{ nm}$  in  $7 \text{ fs}$ . The range of intrinsic energy for EM photons is vast. Five  $\text{km}$  radio wave photons travel  $5 \times 10^6 \text{ m}$  in  $17 \text{ ms}$ , while electric and magnetic fields oscillate once. Three *picometer* gamma ray photons also travel  $5,000 \text{ km}$  in  $17 \text{ ms}$ . but while electric and magnetic fields oscillate  $1.7 \times 10^{18}$  times, meaning that gamma photons have  $1.7 \times 10^{18}$  times as much intrinsic energy as a radio wave photon.

Sinusoidal oscillations are widespread in nature, where even objects with mass exhibit wave properties. Planets in the solar system travel with wave-like properties, oscillating speed and position from the sun throughout each orbit. The most important photoelectric event in nature is the absorption of blue green light by chlorophyll in plant photosynthesis. The absorbed photons energize an electric circuit, with ejected electrons from chlorophyll

conducted down a cytochrome protein 'wire' to reduce  $\text{NADP}^+$  for synthesis of carbohydrate. This replaces substrate carbon dioxide in the atmosphere with oxygen. Water re-supplies the electrons to chlorophyll while forming oxygen gas, which is the cathode reaction of the electric circuit, while the reduction of  $\text{NADP}^+$  to  $\text{NADPH}$  is the cathode reaction.

## Acknowledgments

Some of the material discussed here is based on assumptions that nevertheless appear reasonable. The scientists listed who have studied light for several centuries are inspirational, and several professors at the University of CA, San Diego are especially thanked including Andrew A. Benson, Linus Pauling, Jim Arnold, Sheldon Schultz, Nathan Kaplan, Paul Saltman, Harold Urey among others, for without their instruction none of the past 50 years of research in various disciplines would have been possible. I am blessed to have had a father, a steelworker and survivor of the Pearl Harbor attack, who always said "stay in school."

## References

1. Giancola DC (2005) Physics, principles with applications. (6<sup>th</sup> edn), Pearson Prentice Hall, Upper Saddle River, NJ.
2. Maxwell JC (1873) A treatise on electricity and magnetism.

3. Hertz H (1893) Electric waves: Being researches on the propagation of electric action with finite velocity through space. Dover Publications.
4. Sauerheber R, Espinoza E (2018) Characteristic of light: Velocity, massless energy, and special relativity. Optik 168: 974-986.
5. Haidar R (2016) Thomas Young and the wave theory of light. Bibnum.
6. Exploring our Fluid Earth, Light in the Ocean, University of Hawaii.
7. <https://manoa.hawaii.edu/exploringourfluidearth/physical/ocean-depths/light-ocean>
8. Lewis GN (1926) The conservation of photons. Nature 118: 874-875.
9. <https://hypertextbook.com/facts/2000/DannyDonohue.shtml>
10. Isaac N (1998) Opticks: Or, a treatise of the reflexions, refractions, inflexions and colours of light. Also two treatises of the species and magnitude of curvilinear figures. Commentary by Nicholas Humez (Octavo ed.). Palo Alto, Octavo, Calif.
11. Otis AS (1963) Light velocity and relativity; the problem of light velocity, Einstein theory found invalid, A classical theory of relativity. (3<sup>rd</sup> edn), Christian E Burckel and Associates, Yonkers-on-Hudson, NY.

