Magnetostatics at speed c

1.0 Introduction

The number of phenomena which must be explained by a model of the photon is vast. Although most are easily categorized as either wave or particle; the most interesting phenomena, and the most difficult to interpret, possess elements of both. This paper is an attempt to examine these types of experiments and in the process to define more accurately the fine line separating the wave and particle aspects of electromagnetic radiation; or equivalently, the line distinguishing the continuous and discrete properties of photons.

2.0 The independent photon

2.1 Testing the duality hypothesis

There is only one way to conclusively demonstrate the duality of the photon, and that is to show that single photons exhibit wave characteristics. In order to conduct such an experiment a beam of independent photons must first be generated. In 1909 the first experiment claiming to confirm the wave nature of photons was published[1]. Since then many more have followed all arriving at the same conclusion, first expressed by Dirac, that the photon interferes only with itself[2-7]. None of the experiments, however, actually accomplish what is claimed. This is because estimates of the light intensity required to ensure statistically independent photons are without exception erroneous. The mistaken conclusions are a result of carelessness and a lack of attention to detail that is unparalleled in modern science. The causes of the errors remain to this day largely unrecognized.

2.1.1 The detection of photons with photographic film

Photographic emulsions depend on the developability of silver bromide crystals to record the arrival of photons. This occurs in two stages lasting approximately 10^{-6} sec, and is characterized by the ejection of an electron and subsequent neutralization of a silver atom[8-9]. The photographic mechanism acts therefore as a time-averaging effect, so that film is not an efficient means of detecting single photons. There are several other inefficiencies also present in the photographic process which limit its effectiveness. Because the stable size of a developable grain is two atoms, a minimum of three to four photons must be absorbed by a single crystal before it becomes a part of the latent image. The crystals do not fill the entire space of the beam, however, so some photons pass by unabsorbed. The gelatin used to suspend the crystals also absorbs radiation. The summation of all of these effects means that more than 100 photons impinge on the film for each grain that appears in the final image.

Still other losses occur when exposures are made with low intensity light. This is caused by the thermal instability of isolated single atoms of silver in the silver halide lattice. Despite the fact that these effects became known in the science of photography in the early 1960's experiments that use photographic records as evidence of the existence of "photons" continue to be found in the literature.

2.1.2 The limitations of photodetectors

Photodetectors require an amount of energy greater than that of a single photon to initiate the electron cascade leading to a detection event[10]. Furthermore a simple analysis of the properties of electric circuits indicates that photodetectors of all types will be unable in principle to distinguish single photons. This is because the time required to register a single detection event is on the order of 10^{-9} seconds, whereas the photoelectric effect indicates that single photons have periods on the order of 10^{-12} seconds. A third limitation is due to the relatively large physical size of electrodes. As a result it is impossible to measure variations of intensity perpendicular to the direction of propagation. The angular correlation of starlight detected by stellar interferometers provides dramatic evidence of the existence of such an effect for point sources[11].

2.1.3 The concept of "photon"

The evidence provided in the previous section demonstrates conclusively that the registration of a "detection event" is not equivalent to the arrival of a "photon". The combined effect of detector limitations, together with a property of light beams known as "bunching"[12], means that the volume of space sampled by a detection event may contain many billions of photons[13]. In fact the detection of single photons may only be possible at extremely high energy, at the level of gamma rays. Heisenberg cautioned that only what is observable should be used in the formulation of quantum mechanics[14]. Nevertheless experimenters routinely refer to detection events as "photons" without questioning whether their discrete nature may be due in part to a property of the detection process, i.e. a result of the superposition of radiation and detector[15]. The inconsistencies that arise have led some researchers to deny the existence of the photon altogether[16]. A more reasonable course of action would be to stop the practice of equating detection events with photons.

There is also a model of the "photon" based on the time-averaged properties of field, the so-called B(3) field[17]. It is based on the optical Faraday effect which is the rotation of the plane of polarization of a linearly polarized probe beam by a second circularly polarized pump laser. Because this does not occur in free space it describes a superposition state of photons with other matter, rather than the photon as an independent entity.

2.1.4 Inaccurate data analysis

Data presented in previous experiments on the interference of low intensity light were not normalized[1-7]. In order to do this, as the source intensity is lowered the exposure time must be correspondingly lengthened, such that all fringe images represent light accumulations of equal intensity. If this is done the visibility[18] of fringes will be observed to decrease as exposure time increases no matter what type of detector is used. In other words, as the light intensity of the source decreases less interference occurs. The lessening of interference may be explained in two ways. First, because the detection process for low intensity light is non-linear, not all light is registered by detectors. As a result less interference will be registered. Secondly, if interference is caused by the overlapping of photons, fewer photons would interfere at low intensity when less overlapping occurs. We will see in 2.2 that it is most likely that both effects occur.

2.2 A test of the duality hypothesis

When the points listed in 2.1.1 through 4 above are considered nearly all low intensity interference experiments are found to be deficient[19]. These findings led to an improved test of the duality hypothesis taking into account the limitations of detectors. The initial step in the experiment was to produce a diffraction pattern using coherent light and a 20 second exposure time. A filter was then inserted in the beam so that 2.5 hours were required to obtain an equivalent intensity. No light at all was registered by the film. Exposure time was increased to 17.5 hours and a nearly 10 fold increase in intensity before the film registered the presence of the light beam. A diffraction pattern was still not observed. Even by increasing the exposure to 336.3 hours and a 100 fold increase in intensity the expected diffraction pattern could not be obtained. The same result was also obtained by using a detector of the photoemissive type. The negative results could not confirm or refute the duality hypothesis since they may also be attributed to the physical limitations of detectors.

2.3 Photons observed in a "vacuum"

Quantum theory interprets light waves as probability amplitudes that may be used to predict the locations of photons. In other words, probability waves seem to guide photons to their destinations. Bright fringes are interpreted as locations where large numbers of photons arrive, while dark fringes indicate the arrival of a very small number. As a result it is believed that energy is not conserved locally in an interference fringe[20]. A recent series of four experiments using coherent light; however, shows otherwise[21]. One experiment that is particularly vivid demonstrates that dark fringes contain as much radiant energy as bright fringes. The light from a He-Ne laser is allowed to enter a Michelson interferometer that has been purposely misaligned to create two nearly parallel beams less than .1 mm apart. A short focal length lens then expands and superimposes the beams, causing interference fringes of one cm width to appear about one meter behind the lense (see figure). One of the fringes is selected by using a mirror whose dimensions are about one-half that of a single fringe. The reflected image of the fringe is then passed through a series of three lenses which enlarge and focus it, and then project it onto a screen. It may now be observed that it is immaterial whether a dark or a light fringe is selected. In either case the images of both beams appear on the screen in equal intensity. When the light of one of the beams is blocked by introducing a dark card into the interior of the interferometer the intensity is halved and no interference occurs. The experiment demonstrates that field strength is not a true measure of beam energy, and also that energy is conserved locally. Interference fringes demonstrate therefore that field does not store energy and that the Poynting vector is not a true measure of beam energy.

We are left in a paradoxical state concerning the nature of the electromagnetic field. Classical theory states that field is able to store energy[22]. In this experiment, however, we saw that energy is unchanged by field cancelation. Although the electromagnetic wave cancels at the location of a dark fringe the total radiant energy remains the same. Indeed the same concept may be observed in atoms with respect to the electric field. The field of an electron is canceled if it is captured, but there is no change in the total energy. Similarly the field of photons may cancel at the site of a dark fringe without a net loss. Field need not be assigned an energy density as asserted in classical and quantum theory.

2.4 The physical nature of an electrostatic field

In order to understand what has occurred in the previous experiment it will be necessary to determine precisely how energy is produced by field. Electric field will again serve as our model. If oppositely charged spheres are brought together a spark will jump across neutralizing the field between them. We might expect the spark to be initiated at the negatively charged sphere, due to an excess of electrons, and then proceed to the positively charged sphere. It is possible to find out what actually happens through the use of a "Kerr cell". The optical properties of the Kerr cell may be controlled through the application of an intense electric field so that it acts as an electro-optical shutter to photograph the spark. In this manner it is possible to record the spark during the first billionth of a second of its formation[22].

When the experiment is performed, it reveals that the spark starts in the middle and goes both ways. The result cannot be explained if the spark is conceived of merely as a concentration of electrons. In fact if it were possible to completely isolate the charged sphere from other matter it would not discharge at all. The ionization of the gases that occurs thus allowing the spheres to discharge is caused by the energy residing in the field between the spheres. It indicates that energy density is highest where the <u>intersection</u> of field is greatest. We may interpret the experiment to mean that the ionization of the gas between the spheres that results in a spark is caused by the field from <u>both</u> spheres.

We conclude from the above experiment that isolated field, contrary to what is taught in classical theory, cannot be assigned an associated energy density. In other words, the use of imaginary test charges to define the concept of "field" is improper because the practice mistakenly assumes that lines of electric field need only be imagined as emanating from the electron. The way that a spark is initiated, however, indicates that field effects are only observable when field lines have both a source and a receptor. In other words, the divergence of E is only non-zero locally in nature. Why is it necessary to establish the physical nature of the electric field? If isolated field is devoid of physical content then photons cannot in principle be observed. Field effects are only observable, if two material entities are involved, a source and a receptor. Since the electromagnetic wave is observable it must be composed of field from both the photon and the recipient charge distribution.

3.0 Theory

3.1 Physical consistency

It is physically inconsistent to assign both discrete and continuous properties to the photon, thereby providing it with a dual nature. The paradox of duality may be simplified considerably, however, by carefully distinguishing between wave and particle behavior. Wave behavior is manifested by time-averaged measurements of field intensity, while particle effects are the result of nearly instantaneous changes in energy. Although wave and particle behavior may occur in the same experiment it does not occur at the same time. A model that can account for the continuous and discontinuous properties of photons without invoking duality will be considered "physically consistent".

3.2 Mathematical consistency

The mathematical description of electromagnetic radiation is given by Maxwell's equations.

1) div **E** = rho/epsilon 2) div **B = 0**

3)

The equations 1 to 4 have been experimentally verified so they must be satisfied by all models and descriptions. The functions representing the fields must be single-valued and continuous. throughout space. Due to the experimentally observed physical linearity of electromagnetic fields the mathematical functions must be linear as well. The linear superposition of continuous, single-valued functions is precisely what occurs in Fourier analysis, part of the formalism of both classical and quantum electrodynamics. It is essential therefore to seek a model that is amenable to Fourier analysis.

3.3 Causality

A model meets the conditions of causality if the causal sequence, field to force to acceleration, is uninterrupted and unobscured. *Ad hoc* mechanisms such as the displacement current and "hidden variables" are often used to explain wave effects, but because they have no clear physical basis they must be eliminated from model building. Causality is only satisfied if the observed behavior of matter is accounted for by mathematically defined equations of motion. This condition can only be met in electrodynamics if the interplay of fields, forces, and matter is described in a manner analogous to the way the solar system illustrates gravitational interactions, viz. by using geometric/pictorial methods

3.4 Singularities

Field values in the classical wave equation change polarity as they change phase, and as they do they become singular. Singularities are acceptable in both classical and quantum mechanical descriptions of electromagnetic radiation. However, the existence of singularities in a field theory precludes the possibility of physical description. At the instant in time that a field value becomes zero it has no physical presence and ceases to exist in a geometric/ pictorial sense. The causal description is lost in the process. Therefore a model of the photon that is causal may not include a description of the electromagnetic wave because it includes singular field values.

3.5 Quantum mechanical

There is a fundamental misconception in quantum mechanics that because photons are emitted and detected as discrete entities, electromagnetic fields are also propagated in the form of tiny bundles, or quanta. This cannot be true, however, because a photon's energy depends upon its relative motion with the observer. Observers whose velocity differs will measure different parameters for l, n, E. about the nature of the quantum, i.e. the photon's energy. In other words, the particle properties of a photon are completely arbitrary until it is absorbed or otherwise detected. It is the transformation of a photon's energy that takes place in discrete bundles, or quanta; and this is never evident during propagation. Because fields are detected continuously in terms of time-averages they need not be quantized. Consequently the model of the photon presented here differs from the quantum mechanical model because though energy exchange is quantized, fields are not. The photon is conceived of as a discrete entity with a continuous field, a description that also applies to the electron and other elementary particles. Therefore the characteristic structure of all particles is equivalent.

3.6 Special relativity

3.6.1 Time dilation

A photon that is observed from a point of reference traveling at the speed of light, i.e. from a stationary frame, cannot exhibit internal motion. Due to the Lorentz transformations, proper time not only dilates, it ceases to exist altogether. Time must be totally eliminated from all consideration as a parameter for entities traveling at speed c. In other words, once the photon is emitted, once it exists, all change ceases until it encounters matter. In the photon's frame, emission is instantaneously followed by detection. Interpreted mathematically this means that equations incorporating time cannot be included in the structural properties of an entity traveling at the speed of light. During propagation the photon's structure is static; it cannot change, nor can it "perceive" motion. The photon exhibits wave behavior, but it cannot be wave-like. How will transverse wave motion be reproduced by a model that does not include time? There is no contradiction if wave motion is caused by longitudinal motion. The wing of an airplane, for example, causes air molecules to exhibit a single transverse oscillatory movement as it forces them out of the way in a direction perpendicular to its path.

3.6.2 Length contraction

The Lorentz transformation for length requires that the photon does not extend beyond the distance represented by the wavelength. This requirement is in conformance with paragraph 2.4 in which it is stated that the coherence properties of radiation cannot be incorporated into a model of the photon.

3.7 General relativity

If photons are conceived of as physically independent entities, then they are already consistent with the requirements of general relativity theory. Particles follow curved paths in four dimensional space-time called "geodesics". In the case of photons the trajectory follows a "null geodesic". In other words, the space-time metric of general relativity applies to the photon externally, as a condition of its motion, rather than to its internal structure.

4.0 A classical field model

The multiplicity of phenomena comprising electromagnetic radiation is enormous. This is often reflected in the way the photon is conceived of by incorporating complexity into its structure. There are hints in the mathematical derivation of classical electrodynamics, however, that a simpler model is possible. It is possible to remove the electric and magnetic fields in Maxwell's equations by using arguments from vector analysis and working backwards from equation 2) to introduce the vector potential **A**. Thus del **B** = 0 implies that

6) $\mathbf{B}(\mathbf{x}) = \text{del X } \mathbf{A}(\mathbf{x})$

This allows the electromagnetic wave to be expressed in terms of the vector potential alone.
7) $\text{del}^2 A - 1/c^2$ etc.

The use of 7) to describe the transverse fields has a distinct advantage since it removes the need for a "displacement current" in physical descriptions of the electromagnetic wave.

The electromagnetic wave is describable therefore by a single variable other than that of energy. The use of the vector potential is also more useful than energy because it provides more detail. If, for example, we let the field geometry of the photon be symbolized by the vector potential **A** as a circular vector directed either clock-wise or counter clock-wise in a plane perpendicular to the direction of motion (see figure 1); then the symmetry precisely accomodates the spin of a photon, whose value is $\pm\hbar$.

Suppose now that a constant vector potential of the type described in figure 1, traveling at speed c, encounters a loosely bound electric charge. To obtain the resultant forces we need to describe the interaction in terms of field by using equations 5) and 6). They imply that the vector potential is equivalent to a static magnetic dipole field whose axis coincides with its velocity vector (see figure 2). The relative motion of photon and electron results in a force imposed perpendicular both to the direction of motion and the direction of the **B** field according to the equation,

8) $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$

where the negative signs due to the relative motion and the charge of the electron cancel (see figure 3). We know from the properties of ordinary magnetic field that no work is performed by these forces so that the energy of a localized magnetostatic field is unaffected by these sinusoidally induced forces. Also it is easily shown that if the photon has the field configuration of a magnetostatic field it exactly reproduces Maxwell's equations for the electromagnetic wave. Such a description also compares favorably with the experiment described in 2.3 demonstrating that pure electric, and by association, pure magnetic field; do not have energy associated with them.

If the emission of photons of the type shown in figure 1 were random in both space and time, the positive and negative components of the induced transverse fields cancel and no radiation at all would be observed. However, the electrons of radiating atoms oscillate sympathetically due to the mutual influence of their fields. This occurs because atoms are situated more closely to each other than the distance of a single wavelength. It causes angular and temporal correlations in the spontaneous emission of photons which lead in turn to the beam properties of coherence length and bunching (see figure 4). It is possible therefore to describe beam properties of classical dimension by using photons with a magnetostatic field.

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