80 618

THE EINSTEIN / DE BROGLIE THEORY OF LIGHT: GAUGE CONDITIONS FOR FINITE PHOTON MASS.

by

M. W. Evans,

Department of Physics,

University of North Carolina,

Charlotte,

NC 28223,

U.S.A.

ABSTRACT

In the Einstein / de Broglie theory of light, the rest mass of the photon, m_0, is non-zero. It is shown that this is consistent with gauge invariance of the second kind provided $A_\mu A_\mu = 0$, where A_μ is the electromagnetic potential four-vector, a condition which is derived from the Dirac gauge for vanishingly small photon radius, r_μ.

Letter 1

INTRODUCTION.

The rapidly accumulating experimental evidence for finite photon mass, and by implication, for the Einstein / de Broglie theory of light, has recently been reviewed by Vigier {1} and by Huang {2}, using data from the solar system {3}, and from cosmology {4}. Non-zero m_0 was first proposed by Einstein {5} and the theory of light for $m_0 \neq 0$ was developed by de Broglie {6}. For $m_0 \neq 0$, the d'Alembert equation is replaced by the Einstein / de Broglie / Proca equation

$$\Box A_\mu = -\xi^2 A_\mu \tag{1}$$

for the four-potential A_μ. Here

$$\xi = \frac{m_0 c}{\hbar} \tag{2}$$

where c is the speed of light and $\hbar$ the reduced Planck constant. For $m_0 \sim 10^{-68}$ kgm. {1}; $\xi \sim 10^{-26}$ m^{-1}. Eqn (1) produces longitudinal magnetic and electric fields, as first shown {1} by de Broglie and Schrödinger, and discussed by Moles and Vigier {7} and Bass and Schrödinger {8}. For example,

$$\boldsymbol{B}^{(3)} = \boldsymbol{B}^{(0)} exp(-\xi Z)\boldsymbol{k} \tag{3}$$

is a solution of eqn. (1). Eqn. (3) describes a longitudinal, Z axis, phase independent, magnetic flux density in vacuo, whose scalar amplitude is B^{0} in tesla. In eqn. (3), **k** is an axial unit vector. Since $\xi \sim 10^{-26} m^{-1}$, eqn. (3) becomes, for all practical purposes,

$$\boldsymbol{B}^{(3)} = B^{(0)}\boldsymbol{k} \tag{4}$$

identical with the novel longitudinal solutions in vacuo of the MAXWELLIAN field recently proposed by Evans {9-12}. This letter shows that finite m_0 is consistent with the fundamental principle {13, 14} of gauge invariance in field theory. It is usually asserted in the literature that gauge invariance implies identically zero photon mass. It is shown in the first part of this Letter that this assertion is not valid, and that gauge invariance of the second kind {13,14} is maintained for non-zero m_0, provided:

$$A_{\mu}A_{\mu} = 0 \tag{5}$$

a condition which is derived as an excellent approximation to the Dirac gauge {1}, an approximation which holds for all practical purposes. The second part of the Letter implements eqn. (5) in the context of Glashow / Weinberg / Salam (GWS) and SU(5) theories {2} of unified fields.

1. DERIVATION OF EQN. (5) FROM THE DIRAC GAUGE.

In the Einstein / de Broglie theory of light {1}, photons are massive bosons, PARTICLES, which are controlled, or piloted, by real, spin one, electromagnetic fields. The photons are the only directly observable elements of light, and behave as relativistic particles with finite rest mass, m_0. Their internal motion is controlled by the Guiding Theorem of de Broglie {1}:

$$h\nu_0 = m_0 c^2 \tag{6}$$

so that they beat in phase {1} with the surrounding electromagnetic field. Therefore light is also constituted {1} by electromagnetic WAVES, which for all practical purposes obey Maxwell's equations in the limit $m_0 \rightarrow 0$. For $m_0 \neq 0$, the fields obey eqn. (1), and the Dirac gauge {1}:

$$r_\mu r_\mu = constant \tag{7}$$

where r_μ is the photon radius four-vector. In the photon's rest frame $r_\mu p_\mu = 0$, where p_μ is its energy-momentum four-vector in Minkowski spacetime. **Therefore waves (electromagnetic fields) and particles (photons) co-exist in the Einstein / de Broglie theory of light**, an interpretation which has recently been found {1} to be consistent with contemporary experiments on light. The electromagnetic DE BROGLIE / PROCA field for an uncorrelated photon is represented {1} by:

$$A_\mu = A^{(0)} r_\mu \exp(R + \frac{iS}{\hbar}) \tag{8}$$

i.e. by a complex vector wave, of amplitude $A^{(0)}$, which can be split into transverse and longitudinal parts:

$$A_\mu = A_\mu^{(T)} + A_\mu^{(L)} = A^{(0)} (r_\mu^{(T)} + r_\mu^{(L)}) \exp(R + \frac{iS}{\hbar}) \tag{9}$$

and

$$A_\mu A_\mu^* = A^{(0)2} r_\mu r_\mu \exp(2R) \tag{10}$$

Since the magnitude of the spacelike part of r_μ is about 10^{-22}m, it follows that:

$$A_\mu A_\mu^* \sim 0 \tag{11}$$

for all practical purposes. This is eqn. (5) for complex A_μ; and it is seen that that equation is a limiting form of the Dirac gauge for $|r_\mu| \rightarrow 0$. This result is consistent with an earlier treatment by Moles and Vigier {7}.

Eqn. (5) can also be derived using the Maxwellian field by noting that the contribution of A_μ to the lagrangian {13,14} is:

$$\mathfrak{L}_4 = -\frac{1}{4}F_{\mu\nu}F_{\mu\nu} + \frac{1}{2}m_0^2 A_\mu A_\mu \qquad (12)$$

where $F_{\mu\nu}$ is the electromagnetic four-tensor. The term $\mathfrak{L}_4$ is invariant to gauge transformation of the second kind {13,14} if and only if the second term on the right hand side of eqn. (12) vanishes, which for non-zero m_0 immediately implies equation (5), with $A_\mu \neq 0$.

Therefore gauge invariance does not imply $m_0 = 0$ in the Maxwellian field.

From eqn. (5), for $m_0 \neq 0$; defining $A_\mu \equiv (A, \frac{i\phi}{c})$ in S.I. units, it follows that

$$\phi = c|A| \qquad (13)$$

Furthermore, it is well known {13} that the EBP equation (1) implies mathematically the Lorentz condition:

$$\nabla \cdot A + \frac{1}{c^2}\frac{\partial \phi}{\partial t} = 0 \qquad (14)$$

which with eqn. (13) leads to

$$\frac{\partial A_\mu}{\partial x_\mu} = 0; \quad i.e. \quad \nabla \cdot A + \frac{1}{c}\frac{\partial |A|}{\partial t} = 0. \tag{15}$$

An important implication of eqns. (13) and (14) is that **the Coulomb gauge is inconsistent with finite photon mass,** because in that gauge $\phi = 0$, and $\mathbf{A} \neq 0$, directly contradicting eqn. (13). The Lorentz and Dirac gauges are, however, consistent with $m_0 \neq 0$. **Since $m_0 \neq 0$ is consistent with experimental data {1,2}, the Coulomb gauge should be abandoned, and the existence of longitudinal solutions {9-12} such as eqn. (3) accepted as being physically meaningful.** The notion of zero photon mass should be abandoned as physically obscure and inconsistent with experimental data {1,2}.

2. IMPLEMENTATION OF EQN. (5) IN GWS AND SU(5) UNIFIED FIELD THEORY.

Huang {2} has recently discussed the implications of finite m_0 in unified field theory. In the GWS model {2}, finite m_0 leads to Huang's eqn. (2.17) {2}:

$$\bar{A}_\mu = A_\mu - \sqrt{2}\,\epsilon\rho\,\sin\theta_W (W_\mu^+ + W_\mu^-) \tag{16}$$

where θ_W is the Weinberg angle, $W_\mu^\pm$ are charged intermediate boson potentials, ϵ and ρ are parameters of the Higgs field, defined by Huang's eqn. (2.6), and in which $\epsilon \to 0$ for $m_0 \to 0$, whereupon eqn. (16) reduces to the standard GWS model in which photon mass is set to zero {13}:

$$\bar{A}_\mu = A_\mu = W_\mu^{(3)}\,sin\theta_W + X_\mu\,cos\,\theta_W \tag{17}$$

where $W_\mu^{(3)}$ and X_μ are the standard GWS gauge potentials. It is clear therefore that the new gauge condition, eqn. (5) of this Letter, results in new inter-relations between the gauge potentials of the GWS model for finite m_0, described by eqn. (16).

Similarly, in the SU(5) grand unified field theory {2} for finite m_0, A_μ is defined by Huang's eqn. (3.24):

$$\bar{A}_\mu = A_\mu + \epsilon_1\epsilon_2\sqrt{12}\,(\bar{W}_\mu^+ + \bar{W}_\mu^-) \tag{18}$$

where ϵ_2 is associated with the mass of the photon and ϵ_1 with other gluonic contributions. The effect of eqn. (5) is to introduce an extra relation between the terms appearing in eqn. (18).

DISCUSSION.

The acceptance of $m_0 \neq 0$ implies the gauge condition (5), so that A_μ becomes the fundamental electromagnetic field four-vector, implying that the electric and magnetic components of the field are each fully covariant four vectors, E_μ and B_μ respectively, in Minkowski spacetime. These four-vectors have physically meaningful longitudinal spacelike components {9-12}. Comparison of eqns. (3) and (4) shows that these are identical for all practical purposes in the de Broglie / Proca and Maxwellian fields. The numerous experimental consequences of this deduction have been detailed in the literature {9-12}, using well defined relations between the longitudinal and transverse spacelike components of E_μ and B_μ in the Maxwellian field. These are for all practical purposes the same in the de Broglie / Proca field, because the mass of the photon is very small. The Lie algebraic structure of these relations is discussed in the accompanying Letter {15}.

ACKNOWLEDGEMENTS

Prof. J.-P. Vigier is thanked for illuminating correspondence, preprints, and key suggestions during the course of this work.

REFERENCES.

{1} J.-P. Vigier, "Present Experimental Status of the Einstein / de Broglie Theory of Light.", preprint of the Tokyo Conference paper, 1992, communicated to the author from Institut Henri Poincaré, Univ. Pierre et Marie Curie, Paris, 4th Jan., 1993.

{2} J.-C. Huang, J. Phys. G, Nucl. Phys., **13** (1987) 273.

{3} L. Davis, A. S. Goldhaber and M. M. Nieto, Phys. Rev. Lett., **35** (1975) 1402.

{4} G. B. Chibisov, Sov. Phys.-Usp., **19** (1976) 624.

{5} A. Einstein, Werk. Deutsch. Phys. Ges., **18** (1916) 318.

{6} L. de Broglie, "La Mecanique Ondulatoire du Photon." (Gauthier-Villars, Paris, 1936).

{7} M. Moles and J.-P. Vigier, Comptes Rendues, **276** (1973) 697.

{8} L. Bass and E. Schrödinger, Proc. R. Soc., **232A** (1955) 1.

{9} M. W. Evans, Physica B, **182** (1992) 227, 237, in press.

{10} M. W. Evans, "The Photon's Magnetic Field." (World Scientific, Singapore, New Jersey, London, 1993).

{11} M. W. Evans, in vol. 85(B) of M. W. Evans and S. Kielich (eds.), "Modern Nonlinear Optics.", a special topical issue of I. Prigogine and S. A. Rice, (eds.), "Advances in Chemical Physics." (Wiley Interscience, New York, 1993), vols. 85(A) to 85(C), in press.

{12} M. W. Evans and F. Farahi, Phys. Rev. E, in press.

{13} L. S. Ryder, "Quantum Field Theory." (Cambridge Univ. Press, Cambridge, 1987, 2nd. ed.).

{14} L. S. Ryder, "Elementary Particles and Symmetries." (Gordon and Breach, London, 1986, 2nd. ed.).

{15} M. W. Evans, Phys. Lett. A, accompanying letter.