

# Determination of photon mass from Compton scattering

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The theory of the Compton effect is extended straightforwardly to include consideration of photon mass and the de Broglie Einstein equations introduced by de Broglie in the years about 1922–1924. The theory is used to infer an analytical expression for photon mass in terms of the well known observables of Compton scattering. This means that the mass of the photon can be measured experimentally for the first time in a routine laboratory experiment. The theory is tested against experimental data for gamma ray Compton scattering. Photon mass is a central prediction of Einstein Cartan Evans (ECE) unified field theory, and the unequivocal existence of photon mass refutes the obsolete standard model in many ways. The photon mass is determined at each scattering angle, and the results discussed in terms of consequences for modern physics.

*Keywords:* Photon mass, Compton effect, ECE theory.

## 1. Introduction

The question of whether particles of light have mass has been asked in natural philosophy for centuries, starting with theories such as the corpuscular theory of Newton and contemporaries, based in turn on older ideas back to classical times. In the early twentieth century, Planck and Einstein introduced the concept of the photon, the quantum of light energy. It was proposed by Einstein and others, notably in about 1906, that the photon has mass. This concept was extended by de Broglie in 1922–1924 [1, 2] to the idea of a photon with momentum, and the quantum of momentum. This work by de Broglie resulted in what are known as the de Broglie–Einstein equations, in which ideas from special relativity and the Planck / Einstein quantum theory converge in a simple way. These equations assert that there exists an identically non-zero photon mass  $m$ . In about 1922 Compton

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scattered X rays from a foil and found that the scattered radiation supported the idea that there exist quanta of energy and momentum in electromagnetic radiation of any frequency.

At that point the idea of photon mass should have been tested with data from Compton scattering, now a routine undergraduate experiment. This long delayed test of modern physics is given in this paper, by using the theory of Compton scattering with the de Broglie Einstein equations. In Section 2 the resulting set of equations is solved for the photon mass  $m$  in terms of the observables of Compton scattering: the incident angular frequency  $\omega$  in radians per second, the scattered angular frequency  $\omega'$ , and the angle of scatter  $\theta$  in radians. Photon mass is a central idea of ECE theory [3–12] but in the obsolete physics, known hyper-optimistically as ‘the standard model’, the idea crept in that the photon mass is identically zero. Despite this, the particle physics group gives an upper limit for photon mass in its tables. The idea of identically zero photon mass is evidently self contradictory, the assertion of zero mass is made to force agreement with, for example,  $U(1)$  sector gauge theory [13], now known from the development of ECE theory ([www.aias.us](http://www.aias.us)) to be a mathematically incorrect theory. Limits on the Coulomb law and limits on observable frequency [14] are often used to vaguely enforce the idea of zero or very small photon mass. In this paper a clear and unequivocal equation for photon mass from the Compton effect is given for the first time. This is a precise result based on the use only of the relevant fundamental theories of modern physics: special relativity and Planck/Einstein/de Broglie quantization [14].

## 2. Theory of Compton scattering with finite photon mass.

The textbook theory of Compton scattering [14] of a photon from an electron gives the elegant result:

$$\lambda_f - \lambda_i = \lambda_c (1 - \cos\theta) \quad (1)$$

where  $\lambda_i$  is the incident electromagnetic wavelength,  $\lambda_f$  is the scattered electromagnetic wavelength and where

$$\lambda_c = \frac{\hbar}{Mc} \quad (2)$$

is the Compton wavelength of the electron of mass  $M$ . Here  $\hbar$  is the Planck constant and  $c$  is a universal constant always known in the textbook theory as the ‘speed of light in vacuo’. Here  $\theta$  is the scattering angle, the angle subtended by the scattered radiation with the line of the incident radiation. The result (1) is obtained from the equation of conservation of total energy and total momentum when the electron is initially at rest, having initially no momentum. Therefore,

from conservation of the total energy of photon plus electron:

$$\hbar\omega + Mc^2 = \hbar\omega' + (M^2c^4 + c^2p'^2)^{1/2} \quad (3)$$

where the initial and final energies of the photon are respectively  $\hbar\omega$  and  $\hbar\omega'$ . The initial energy of the electron is its rest energy in special relativity:

$$E = Mc^2 \quad (4)$$

and the final energy of the electron is:

$$E = (c^2p'^2 + M^2c^4)^{1/2} \quad (5)$$

where  $\mathbf{p}'$  is its final momentum. From the conservation of total momentum of photon and electron:

$$\mathbf{p}' = \hbar(\mathbf{k} - \mathbf{k}') \quad (6)$$

where  $\mathbf{k}$  is the initial wave-vector of the photon and  $\mathbf{k}'$  the final wave-vector. From elementary vector analysis [15]:

$$p'^2 = \hbar^2(\mathbf{k} - \mathbf{k}') \cdot (\mathbf{k} - \mathbf{k}') = \hbar^2(\mathbf{k}^2 + \mathbf{k}'^2 - 2\mathbf{k}\mathbf{k}' \cos\theta) \quad (7)$$

and Eq. (1) is obtained by solving Eqs. (3) and (7) simultaneously, eliminating the factor  $p'^2$ , i.e. eliminating the final electron momentum. In this process it is assumed that:

$$\mathbf{k} = \frac{\omega}{c}, \quad \mathbf{k}' = \frac{\omega'}{c} \quad (8)$$

and this assumption implies that the photon travels at  $c$ , and that the photon has no mass.

The assumption (8) diametrically contradicts the foundations of modern physics, foundations which rest on the de Broglie–Einstein equations [1, 2]:

$$E = \hbar\omega = \gamma mc^2, \quad (9)$$

$$\mathbf{p} = \hbar\mathbf{k} = \gamma m\mathbf{v}, \quad (10)$$

which are simple combinations of special relativity and quantum theory. Here  $E$  is the total relativistic energy of one photon, and  $\mathbf{p}$  is the relativistic momentum of one photon. The magnitude of the velocity of the photon is  $v$ , and this is

not  $c$ . The latter is the maximum speed attainable by the photon,  $c$  being the usual fundamental constant of the standards laboratories, fixed by treaty. The Lorentz factor is:

$$\gamma = \left(1 - \frac{v^2}{c^2}\right)^{-1/2}. \quad (11)$$

At different angular frequencies  $\omega$  and  $\omega'$ , the photon has different velocities  $v$  and  $v'$ , but the mass  $m$  of the photon is the fixed mass of an elementary particle. Therefore:

$$\left. \begin{aligned} \hbar \omega &= \gamma c^2, & \hbar \mathbf{k} &= \gamma m v, \\ \hbar \omega' &= \gamma' c^2, & \hbar \mathbf{k}' &= \gamma' m v', \end{aligned} \right\} \quad (12)$$

and the relation between  $\omega$  and  $\mathbf{k}$  is:

$$\mathbf{k} = \frac{v}{c^2} \omega, \quad \mathbf{k}' = \frac{v'}{c^2} \omega' \quad (13)$$

The two Lorentz factors  $\gamma$  and  $\gamma'$  are related to the two angular frequencies by:

$$\frac{\gamma'}{\gamma} = \frac{\omega'}{\omega}. \quad (14)$$

The equation of conservation of total energy is therefore:

$$\gamma m c^2 + M c^2 = \gamma' m c^2 + (c^2 p'^2 + M^2 c^4)^{1/2} \quad (15)$$

and the equation of conservation of momentum is Eq. (7), in which Eqs. (11) to (14) are used to give:

$$c^2 p'^2 = \frac{\hbar^2}{c^2} (\omega^2 v^2 + \omega'^2 v'^2 - 2\omega\omega' v v' \cos\theta). \quad (16)$$

Eliminating the electron momentum gives:

$$(m c^2 (\gamma - \gamma') + M c^2)^2 - M^2 c^4 = \frac{\hbar^2}{c^2} (\omega^2 v^2 + \omega'^2 v'^2 - 2\omega\omega' v v' \cos\theta) \quad (17)$$

in which:

$$\gamma - \gamma' = \left(1 - \frac{\omega'}{\omega}\right) \gamma := \Omega \gamma \quad (18)$$

from Eq. (14), which also gives:

$$\left(1 - \frac{v'^2}{c^2}\right) = \left(\frac{\omega}{\omega'}\right)^2 \left(1 - \frac{v^2}{c^2}\right). \quad (19)$$

The fundamental energy equation of the de Broglie Einstein theory gives:

$$\hbar \omega = mc^2 \left(1 - \frac{v^2}{c^2}\right)^{-1/2}. \quad (20)$$

From Eqs. (17), (19) and (20) is obtained

$$\omega^2 v^2 + \omega'^2 v'^2 - 2\omega\omega'vv' \cos\theta = A \quad (21)$$

where:

$$A = \Omega^2 \omega^2 c^2 \left(1 + \frac{2Mc^2}{\hbar \omega \Omega}\right). \quad (22)$$

Equation (21) can be solved simultaneously with:

$$1 - \frac{v'^2}{c^2} = \left(\frac{\omega}{\omega'}\right)^2 \left(1 - \frac{v^2}{c^2}\right) \quad (23)$$

to eliminate  $v'$ , leaving as follows an equation for  $v$  and therefore  $m$  in terms of experimental observables.

From Eq. (23):

$$v'^2 = c^2 \left(1 - \left(\frac{\omega}{\omega'}\right)^2 \left(1 - \frac{v^2}{c^2}\right)\right) \quad (24)$$

and using this equation in Eq. (21) gives the result:

$$\omega^2 v^2 - \omega \omega' v v' \cos \theta = B \quad (25)$$

where:

$$B = \frac{1}{2} \left( A - c^2 \left( 1 - \left( \frac{\omega}{\omega'} \right)^2 \right) \omega'^2 \right). \quad (26)$$

Therefore:

$$v' = \frac{\omega^2 v^2 - B}{\omega \omega' v \cos \theta}. \quad (27)$$

From Eq. (14):

$$\frac{v^2}{c^2} = 1 - \left( \frac{\omega'}{\omega} \right)^2 \left( 1 - \frac{v'^2}{c^2} \right), \quad (28)$$

i. e.:

$$\frac{v^2}{c^2} = 1 - \left( \frac{\omega'}{\omega} \right)^2 + \frac{1}{c^2} \left( \frac{\omega'}{\omega} \right)^2 \left( \frac{\omega^2 v^2 - B}{\omega \omega' v \cos \theta} \right)^2 \quad (29)$$

which is a quadratic in  $v^2$  :

$$\frac{v^4}{c^2} (1 - \cos^2 \theta) + \left( \left( 1 - \left( \frac{\omega'}{\omega} \right)^2 \right) \cos^2 \theta - \frac{2B}{c^2 \omega^2} \right) v^2 + \left( \frac{B}{c \omega^2} \right)^2 = 0. \quad (30)$$

The solution of this quadratic is:

$$v^2 = \frac{1}{2a} \left( -b \pm (b^2 - 4ac')^{1/2} \right) \quad (31)$$

where:

$$a = \frac{1}{c^2} (1 - \cos^2 \theta), \quad (32)$$

$$b = \left( 1 - \left( \frac{\omega'}{\omega} \right)^2 \right) \cos^2 \theta - \frac{2B}{c^2 \omega^2}, \quad (33)$$

$$c' = \left( \frac{B}{c\omega^2} \right)^2. \quad (34)$$

Finally, the photon mass is found unequivocally from:

$$m = \frac{\hbar \omega}{c^2} \left( 1 - \frac{v^2}{c^2} \right)^{1/2}. \quad (35)$$

Since  $v^2$  must be positive and real valued, it is straightforward to select the relevant root of the quadratic.

The derivation of the photon mass from the Compton effect is of great importance because it provides an unequivocal test of modern physics by evaluating  $m$  at various scattering angles in a Compton effect experiment. The results must be such that the photon mass  $m$  is constant and must be such that  $v$  has physical meaning. A recent experiment on the Compton effect [15] was chosen at random to test the theory. This experiment took place at an incident gamma ray angular frequency:

$$\omega = 1.0052 \times 10^{21} \text{ rad s}^{-1}. \quad (36)$$

The measured scattering angles and frequencies are given in Table 1. This is a gamma ray Compton scattering experiment, the original data having been converted to S.I. units using:

$$1 \text{ eV} = 1.51924 \times 10^{15} \text{ rad s}^{-1} \quad (37)$$

The comparison of data and theory is given in Section 3.

### 3. Comparison of data and theory

The formulas (24), (31–35) and some auxiliary formulas have been evaluated for the experimental data of  $\theta$  and  $\omega'$  given in Table 1, together with  $\omega$  from Eq. (36). The arguments of the formulas vary widely in the exponents (up to 50 decimal places) so that it was advisable to use atomic units with

$$\hbar = M = 1, \quad c = 137.0360, \quad (38)$$

**Table 1.** Scattered angular frequencies and angles [15]

Angle / radians	Scattered angular frequency $\omega'$
( $\theta$ )	/ ( $10^{20}$ rad / sec)
0.1745	9.832
0.2618	9.583
0.4537	8.831
0.6457	7.940
0.8028	7.157
0.9250	6.597
1.0472	6.111
1.1589	5.615
1.2740	5.253
1.5707	4.416

and an energy conversion factor of

$$1 \text{ Hartree} = 27.211396 \text{ eV.} \quad (39)$$

The results for the velocities  $v$  and  $v'$ , obtained from the scattering data, are plotted in Fig. 1. There are two solutions from the quadratic equation (31). One solution gives values  $v < c$ ,  $v' < c$  and a positive photon mass for all angles, the other solution gives velocities greater than  $c$  and imaginary masses in nearly all cases. Therefore we chose the first solution.

If the de Broglie theory were valid, then  $v$ , the velocity of the incoming photon, should be near to  $c$ . The same should hold for  $v'$  of the outgoing photon. It can be seen that the velocities vary widely and are only of the order of some percent of  $c$  in many cases. This is unphysical; thus, the de Broglie/Einstein theory fails.

The obtained photon masses are shown in Fig. 2. The velocities vary widely, and so does the photon mass  $m$ . The contrary would to be expected from de Broglie/Einstein theory. Furthermore, the value of  $m$  is in the order of the electron mass which is grossly wrong. Therefore, the notion of mass should be replaced by the scalar curvature of ECE theory which is defined by

$$R = \left( \frac{mc}{\hbar} \right)^2. \quad (40)$$



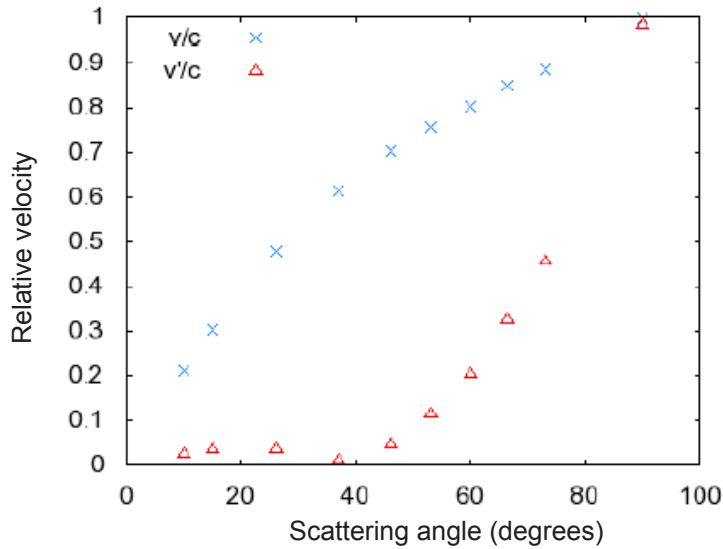


Fig. 1. Relative velocities in dependence of scattering angle  $\theta$  [15].

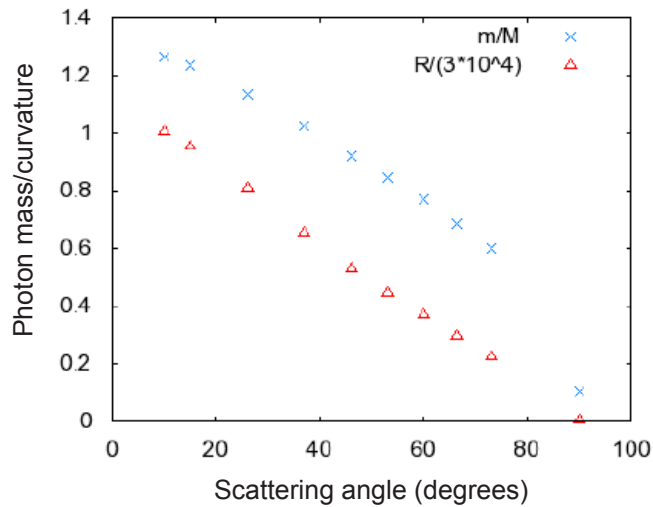


Fig. 2. Relative electron mass and curvature in dependence of scattering angle  $\theta$  [15].

This definition has the advantage that negative and even imaginary masses would be transformed to a physically meaningful curvature term. From Fig. 2 it is seen that curvature varies similar to the mass. As stated above, a varying curvature is physical, but a varying mass is not and proves the failing of de Broglie Einstein theory and foundations of twentieth century physics.

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