Particles without mass: The enigma of the photon

Does the light particle really have no rest mass or are physicists merely unable to detect it?

by Dietrick E. Thomsen

Textbooks of physics say that the photon or light particle has no mass when it is at rest. Therefore it cannot exist at rest, but only in flight. The photon is an ideal medium for carrying messages, since its masslessness means that it travels as fast as anything in the universe can go, the speed designated by the mathematical symbol c, approximately equal to 300,000 kilometers per second. Furthermore a zero-mass photon means that the effects of electric and magnetic forces extend to infinity, and electrodynamic theory has been built on that assumption.

Physicists always like to prove what textbooks assert. As Dr. Peter Franken of the University of Michigan puts it, they are always "hungry for something to work on that looks like fun." This question looks like fun, not because it is likely to have any severe repercussions in practical matters, but because it has interesting effects in the philosophy and theory of physics.

There is plenty of evidence against any significant photon rest mass. No experiment has ever found a photon with any rest mass within the experiment's limit of accuracy. But negative evidence does not prove zero; there is always room for someone to try a more precise measurement.

In doing so physicists are now running up against one of the characteristic qualities of particle physics: The smaller the effect, the larger the equipment necessary to find it. Where particle masses are concerned, there is a criterion called the Compton wavelength, a way of expressing mass in terms of space. The less mass a particle has, the greater will be its Compton wavelength. In the photon's case the Compton wavelength expresses roughly the distance over which one has to measure to find deviations from theory in the characteristics of electric and magnetic fields.

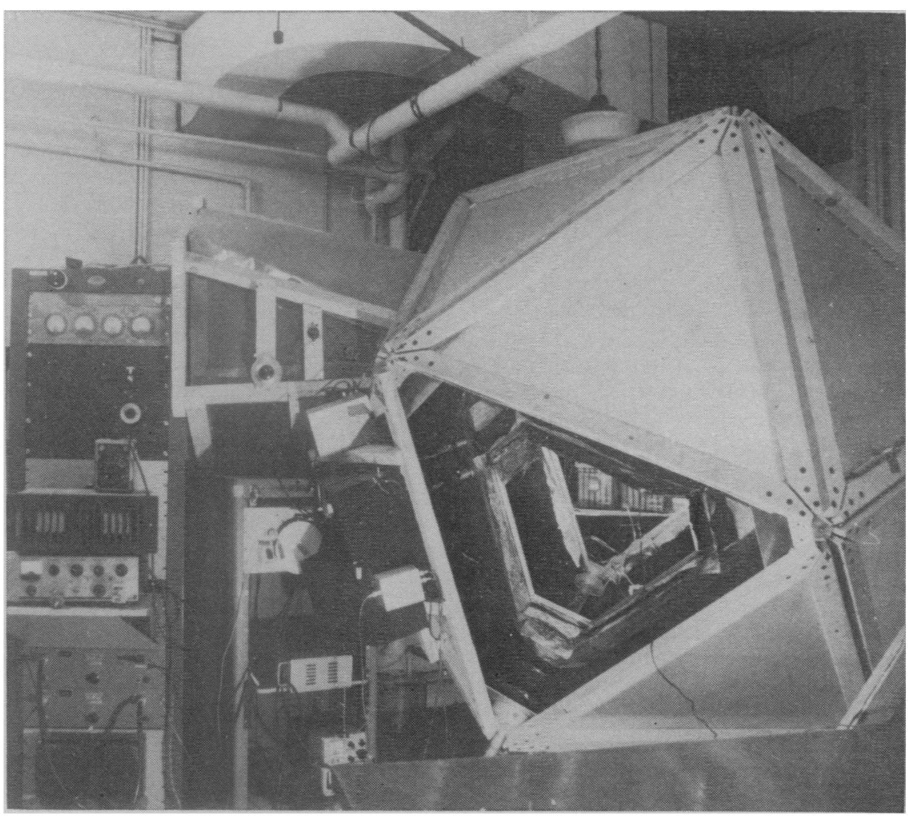
Experiments aboard satellites have shown no deviations on the part of the earth's magnetic field to distances of 550,000 kilometers. This means that the photon Compton wavelength is greater than that, corresponding to a mass less than 4×10^{-48} grams.

To better that in the laboratory, experimenters try to use more complicated situations than the behavior of simple electromagnetic fields, cases where the Compton wavelength does not have such a direct effect. Dr. Franken and Gary W. Ampulski proposed an experiment using electromagnetic induction (SN: 1/30/71, p. 83).

An alternating current flowing in a circuit generates an alternating magnetic field in the surrounding space. If a second circuit is within the influence of the field, the field will induce a current in that circuit. Dr. Franken and Ampulski proposed that if there is a photon rest mass, there should be some minimum frequency below which such induction would not take place.

In fact no such minimum was found, but a number of critics have popped up to say that the experiment could not measure a photon rest mass. Several of them point out that what it does prove is that the effects that cause induction move at the speed c even if the photon does not. Dr. Franken says he has no rebuttal to the critics, and commends them for the gentlemanly way they have handled the discussion. "It is a way of conducting debates that we should see more often in physics," he says.

An example of a laboratory experiment that critics generally accept is one done a few months ago by Drs. James E. Faller and H. A. Hill of Wesleyan University and E. R. Williams of Williams College (SN: 5/8/71, p. 322). They used a high-frequency alternating voltage and a set of concentric conducting spheres. The object was to apply the voltage to the outermost of the spheres, and see if the innermost would detect it. Directly this is a test of Coulomb's law that the strength of an electric field is inversely proportional to the square of the distance from the source. But a zero-mass photon is one of the consequences of Coulomb's law, and this experiment says the photon weighs less than 1.6×10^{-47} grams.



Faller, Hill, Williams

Faller, Hill and Williams: Voltage on outer shell was not sensed by innermost.

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Meanwhile Dr. Williams and Dr. David Park of Williams College propose going beyond the earth's magnetic field to that of the galaxy. If photons have rest mass, then a magnetic field running along a spiral arm of the galaxy should decay rapidly—"in minutes," says Dr. Park. The actual field appears to be stable. Physical processes in the galaxy have characteristic times in the millions and billions of years, so there doesn't seem to be a pumping mechanism that could compensate for the hypothetical fast decay, he says. From this one might conclude that the photon Compton wavelength is longer than six light-years and the mass therefore less than 3×10^{-56} grams. But Dr. Park cautions: "We don't know beans about the galactic magnetic field." Recent data contradict each other. "Our knowledge of the field is too shaky for a firm conclusion," he emphasizes.

One reason for all this activity is that, as Dr. Norman M. Kroll of the University of California at San Diego puts it, "We really have no idea from the point of view of theoretical physics why the photon mass should be zero." Coulomb's law was an experimental determination, and modern electrodynamics goes ultimately back to it. Behind it is no known profound philosophical reason; it may be just an accident.

Therefore, Dr. Kroll continues, physicists feel they ought to find out "why it should be zero or that it is not zero."

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Relativistic mass: Any rest mass but zero becomes infinite at speed c.

If it is not zero, he believes, "it could be incorporated into every theory without a ripple"—at least, without changing them conceptually. Some of the numbers and some of the ways of thinking and philosophizing about the theories would have to change.

One theory that will stand is special relativity. All participants in the discussion seem to agree that special relativity can hold up even if light does not go at the "speed of light." A universal limiting speed, *c*, would remain, even if photons never went that fast.

Experiment	Coulomb's Law violation of form r^{2-q} — q	Photon rest mass — m_o
Cavendish (1773)	2×10^{-2}	
Coulomb (1785)	4×10^{-2}	
Maxwell (1873)	4.9×10^{-5}	
Plimpton and Lawton (1936)	2.0×10^{-9}	$\leqq 3.4 \times 10^{-44}$g
Schroedinger (1943)	Test of Ampere's Law from Geo-magnetic Data	$\sim 2 \times 10^{-47}$g
Gintsburg (1963)		$\leqq 8 \times 10^{-48}$g
Nieto and Goldhaber (1968)		$\leqq 4 \times 10^{-48}$g
Cochran and Franken (1967)	9.2×10^{-12}	$\leqq 3 \times 10^{-45}$g
Feinberg (1969)	Dispersion of light	10^{-44}g
Barlett, Goldhagen, Phillips (1970)	1.3×10^{-13}	$\leqq 3 \times 10^{-46}$g
Williams, Faller, Hill (1971)	$(2.7 \pm 3.1) \times 10^{-16}$	$\leqq 1.6 \times 10^{-47}$g
Williams and Park (1971)	Calculation from galactic magnetism	$< 3.4 \times 10^{-56}$g

Faller, Hill, Williams

Photon-mass experiments: Column at right gives upper limit set by each one.

But special relativity has close historical and philosophical connections to the theory of electromagnetism, out of which in fact it grew. "One would hate to see what was the foundation of special relativity removed," says Dr. Michael Nieto of the University of California at San Diego. A whole manner of thinking, which uses light signals as actual and hypothetical tests of special relativity, would have to be revised. Neutrinos, which are also supposed to be massless, might be used instead, but less is known about neutrinos than about photons. Perhaps they too. . . .

In general relativity there might be some more serious effects. Dr. Nieto suggests that a photon with mass might lead to important consequences on a cosmological level related to large-scale interactions between light and gravity.

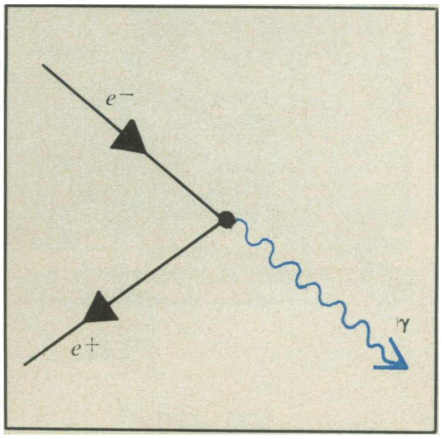
A theory that would suffer only minor readjustment is classical electrodynamics, on which electrical technology is built. Says Dr. Kroll: "You can construct a theory as satisfying as Maxwell's [classical electrodynamics] with a rest mass in it." Dr. Franken concurs. If his experiment had found a photon mass by means of a limiting low frequency, he says, it would have fouled up classical electrodynamics, since people working with low-frequency circuits would have had to pay attention to it. But since it didn't, there's no problem.

Finally, a photon mass could have some bearing on the theory of quantum electrodynamics, which has to do with the behavior of electromagnetic forces on the particle-physics level. The original form of this theory predicted a photon with an infinite rest mass. This was manifestly inappropriate, and a way was found to redo the mathematics so that the mass came out zero. The result doesn't quite satisfy everybody.

"The present situation in quantum electrodynamics requires far-reaching changes," says Dr. Park. "The whole modern field tends to evade the question" of photon mass.

One of the ways of giving a physical explanation of a zero-mass photon within quantum electrodynamics begins with the proposition that a large part of a particle's mass comes from its interaction with the force fields that surround it. The field acts on the particle; the particle reacts back on the field, and the tension between them generates energy that appears as mass of the particle.

The infinite photon mass in quantum electrodynamics disappears, theorists



Electron plus positron yields photon.

suggest, when the influence of other force fields beside the electromagnetic one are considered. The fields conspire together to render the photon mass zero. Or nearly so. Dr. Park suggests that one reason to search for a photon mass is to check the effectiveness of this conspiracy. "If the mass really is zero," he says, "it's one hell of a fine conspiracy." It would mean, he says, that zero rest mass for the photon is not an accident but that the universe is put together in such a way that the photon cannot have a rest mass. □