Chapter 17

MATTER, MASS AND ELECTROMAGNETIC MASS

There are many theories and definitions concerning the concepts of matter and mass. One artificial and ad hoc *theory, electromagnetic mass, has been incorporated into many current theories, including Special Relativity. However, it turns out that electromagnetic mass is not really a mass of matter, but rather only a theoretical resistance of the medium through which matter and some electromagnetic phenomena pass.*

A. What is Matter and what is Mass?

The Greek word 'maza' originally meant an inferior quality of bread.[1] Archimedes used the related word 'masse' to mean a lump or block. The Latin word of the early Christian Church, 'massa,' expanded the meaning to include an 'aggregation of bodies.' (Jammer, 1961, pp. 7 – 9, 29) In the writings of Aristotle, the word 'materia' originally meant timber. (*Id*., p. 19) Then, in the 13th century, a disciple of Thomas Aquinas, Aegidius Romanus, conceived the idea of *quantitas materiae* ('quantity of matter') "as a measure of mass or matter, independent of determinations of volume or weight."[2] (*Id*., p. 45) Throughout most of recorded history, matter and mass were thought of as synonymous terms. For example, Galileo considered 'mass' as "another name for matter itself." (Jammer, 1961, pp. 51 – 52)

Kepler, Galileo, Descartes, and Newton, working separately, created the concept of inertia, which in concert with Newton's second law of motion would ultimately result in the concept of 'inertial mass.' (Chapter 4) Kepler described inertia as "something similar to weight" which "matter must have;" the "repugnance [resistance of] inertia or opposition to motion is a characteristic of matter; it is stronger, the greater the quantity of matter in a given volume." (*Id*., pp. 55, 56) Newton equated mass (*corporis vel massae*)

[1] Similar words in Hebrew and Egyptian meant substantially the same thing.
[2] The 15th century concept of 'impetus' required the concept of quantity of matter.

with the quantity of matter (*quantitas materiae*), however his three laws of motion made no explicit mention of mass. The concept of mass is only implied by the acceleration of a body in his second law.[3] (*Id*., p. 65) Thus, it was left for Euler in 1736 to explicitly state a formula for 'inertial mass:' "Force equals mass times acceleration." (Jammer, 1961, p. 89) Reciprocally, m = F/a. Inertial mass is sometimes also referred to as 'mechanical mass.' (see Feynman, 1964, p. 28-3)

During the early part of the 18th century, German scientist Gottfried Leibniz (1646 – 1716) invented complicated and confusing theories of mass and matter. In the mid 18th century, Immanuel Kant criticized Newton's concepts, but failed to advance the concept of mass. The idea of the indestructibility and 'conservation' of matter or mass was implicit in Newton's theories, and French physicist Antoine Lavoisier (in 1789) extended this notion of conservation to chemical reactions,[4] but he failed to define either matter or mass. (Jammer, 1961, pp. 85 – 86) During the 19th century, French physicist Bané de Saint-Venont, Maxwell, Ernst Mach and Hertz all attempted to invent new definitions of mass. Mach and Saint-Venont each rejected *quantitas materiae*, but failed to come up with an improved alternative, although Mach did arrive at an acceptable theoretical construct.[5] (*Id*., p. 100) Maxwell's theory assigned a priority of force over mass, and Hertz's definition essentially redefined mass by weight. (*Id*, pp. 103, 105)

During the early 20th century, the Italian school attempted numerous contrived definitions of mass but without much success. Their attempts resulted in several definitions of 'gravitational mass,' which we shall briefly discuss in Chapter 40. (*Id*., p.

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[3] Newton referred to the words 'body,' 'mass' and 'matter' as meaning the same thing, and he defined its quantity as 'arising from its density and bulk conjointly.' (Newton, *Principia* [Motte, Vol. 1, p. 1])

[4] In other words, Lavoisier asserted that the same quantity of matter is present after a chemical reaction as was present before such reaction.

[5] Mach's definition was equivalent to Newton's third law of motion, but it did not really describe what mass is. (Jammer, 1961, p. 121)

110) Later, scientists Hans Herm (in 1938), Pendse (in 1939), Herbert Simon (in 1947), and Alfred Tarshi attempted to define the concept of mass as a 'primitive' concept, without using other concepts to make it meaningful. (Jammer, 1961, pp. 112 – 119) Two of such attempts merely resulted in mass ratios that can be obtained by Euler's formula, and the others attempted to define mass by statistical inference. All involved the motion of bodies by reason of force. Jammer concluded that in general: "no attempts to formalize Newtonian mechanics by a precise explicit definition of mass have been very successful," and he gave as an example of such circular definitions:

> "We obtain our knowledge of forces by having some theory about masses, and our knowledge about masses by having some theory about forces." (*Id*., p. 120)

Thus, it may be impossible to devise a meaningful qualitative definition of mass without resort to an empirical, mechanically covariant and quantitative interaction between the variables of Euler's formula: $m = F/a$.

Definitions of 'matter' have been equally frustrating. Is it atomic in nature, composed of quarks and gluons or strings (quantum mechanics definitions)? Is it electromagnetic in nature? Is it merely stored energy? Is it the effect of an interaction between particles and some phenomenon called the Higgs field? (Close, pp. 192 – 193) Does matter even exist? There are many very confusing theories concerning both matter and mass. As one sage writer concluded: "Mass is a mess."

B. What is Electromagnetic Mass?

'Electromagnetic mass' is a highly theoretical concept that was concocted by physicists and mathematicians around the turn of the 20th century. The reason why we need to discuss and understand this concept a century later, is two-fold: 1) Einstein based his concepts of 'relativistic mass' and 'relativistic dynamics' on electromagnetic mass, and 2) vestiges of electromagnetic mass remain with us in the form of other dubious theories.

Remember that in Newtonian mechanics, the concept of inertial mass (m) was defined and empirically quantified by Euler's formula: $m = F/a$.[6] However, during the mid 19th century it was realized that this formula was only an idealization, because it ignored the resistances present in the body's environment, such as air, radiation and friction. A body's (or a particle's) environment of resistances were later referred to by the terms 'medium' or 'field.' Because of such inertial resistances, the acceleration of a terrestrial body is less than the idyllic acceleration that theoretically exists in empty space. Therefore, the terrestrial mathematical inertial mass that is empirically defined by the factor F/a is greater than the idyllic mass in empty space. (see Jammer, 2000, p. 32) This 'greater mathematical mass,' its magnitudes and its theoretical variations are the subjects of our discussion in this chapter.

When the influence of environmental resistances upon a body's acceleration was realized in the mid 19th century, this phenomenon at first resulted in a concept known as 'hydrodynamical mass.' Every body that moves through a fluid medium quite naturally experiences a resistance to its motion. Therefore, the force exerted on the body by the medium results in less than an idyllic mathematical acceleration ($a = F/m$), the magnitude of which depends upon "the shape of the body and the nature of the medium." (Jammer, 2000, p. 33) When algebraically expressed in mathematical terms of $m = F/a$, the reduction in acceleration 'a' algebraically resulted in an increase in mass 'm,' and such

[6] In Newtonian mechanics, mass "was a number which was constant, unchanging and invariant with regard to different frames of reference. It only changed when the object itself changed," i.e. burned. (Goldberg, p. 132)

increase has sometimes been called a 'virtual mass.' This mathematical convention of arbitrarily referring to the effect of an environmental resistance as an increase in the mass (or inertia) of the body moving through such environment (or medium) is the root cause of much of the confusion about mass that has followed. If Euler's equation had simply been changed to m = F/(a – R), where R is the environmental resistance or the resistance of the medium, then much of such confusion (and many dubious theories and interpretations) could have been avoided.

What happens if the medium is not a fluid but rather an electromagnetic field, and the body is a charged particle such as an electron? In 1881, by analogy to the hydrodynamical mass scenario, British physicist J. J. Thompson (1856 – 1940) theorized that the electromagnetic field (induced by the relative motion of the charged particle itself) caused a retardation or resistance to its acceleration that was "<u>equivalent to an increase in mass</u> of the charged moving sphere."[7] (Jammer, 1961, pp. 136 – 137) This type of electromagnetic resistance was later described as 'self-induced.' (see Feynman, 1964, pp. 28-4 through 28-8)

In 1889, a paper published by British physicist Oliver Heavyside (1850 – 1925) dramatically expanded Thompson's analogy to hydrodynamical mass by referring to the theoretical increase in mass <u>as if</u> it was a physically significant phenomenon. For Heavyside, the electromagnetic resistance was "not only analogous to mechanical inertia but an inertial effect *sui generis*. In fact, Heavyside speaks explicitly of an 'electric force of inertia.'" (Jammer, 1961, p. 141)

Whereas, before Heavyside's paper there were mechanical theories of

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[7] In other words, Thompson only conceived of the process "as if" the mass <u>hypothetically</u> increased. (Jammer, 1961, p. 137)

electromagnetism (such as Maxwell's), after the publication of Heavyside's paper there were numerous electromagnetic theories of mechanics which asserted that inertial mass was basically an inductive effect of electrodynamics. (*Id*., pp. 136, 141 – 142, 144) Imaginative concepts of 'electromagnetic mass' and 'electromagnetic momentum' were soon introduced by Poynting, Abraham, Lorentz, Wein, Kaufmann, Poincaré, Bucherer, Einstein, and others. (*Id*., pp. 142 – 145; see Figure 17.1) However, they were only myths, because 'electromagnetic mass' is only a myth. In reality, it is merely an electromagnetic resistance in the environment of a charged particle (i.e. an electron). It might even be more correct to describe the effect as 'electromagnetic inertia.'[8] (see Feynman, 1964, p. 28-10)

C. The Electromagnetic World Picture

The concept of electromagnetic mass ultimately resulted in the theoretical attempt to "explain all processes in nature in terms of convection [electric] currents and their electromagnetic radiation." It was dubbed the 'electromagnetic world-picture' by its most ardent advocate, German mathematical physicist Max Abraham (1875 – 1922).[9] (Jammer, 2000, p. 35) It was necessary for the proponents of this view to describe and deal with mass totally as an electromagnetic phenomenon. (Goldberg, p. 133) This was nothing less than an attempt to strip matter of its substance, and to negate the existence of material mass. As German physicist Walter Kaufmann (1871 – 1947) conjectured: "the total mass of the electron is merely an electromagnetic phenomenon;" and his colleague

[8] In fact, Lorentz did describe the effect as 'electromagnetic inertia.' (see Goldberg, p. 93) According to Lorentz's theory of the electron, electromagnetic inertia was the force exerted by a magnetic field on the electron in the direction perpendicular to its motion. (*Id*., p. 134; see Figure 17.1)

[9] Ether was the fundamental phenomenon of this conceptual view, "charge was the manifestation of forces exerted on the ether," and mass was the result of the inertia of electric charge moving through various fields. (see Goldberg, p. 133)

Max Abraham proclaimed: "the inertia of the electron originates in the magnetic field." (Jammer, 2000, pp. 35, 36) These conjectures may be regarded "as the first field-theoretic treatment of elementary particles." (*Id*., p. 35; see Chapter 34)

In 1901, Kaufmann began experiments to measure the inertia and the mass of electrons that were theoretically moving at speeds near to that of light.[10] Kaufmann was attempting to measure the ratio of the fixed charge of the electron to its mass, as a function of the electron's velocity. He concluded that such ratio decreased as the electron's velocity increased, which he interpreted as an increase of the electron's mass.[11] (see Figure 17.1B) The problem then was to invent a theory that might account for this effect. (Goldberg, p. 134)

In 1902, Abraham postulated that the electron was a rigid sphere.[12] After much conjectured theorizing, he calculated the magnitude of the electromagnetic mass of the electron depending upon its speed and direction of motion. The mass of the electron in its direction of motion relative to the ether he called the 'longitudinal mass.' Since no experiment has ever been devised to measure longitudinal mass, its *ad hoc* theoretical magnitudes remain completely speculative. The electron's mass in the direction perpendicular to its motion Abraham called the 'transverse mass.' After many complicated mathematical calculations he concluded that his *ad hoc* magnitudes for the transverse mass of the electron substantially agreed with Kaufmann's experimental deflection results, even though such results were not certain. (Goldberg, p. 135)

In April 1904, Lorentz published a paper that contained his radical transformation

[10] Kaufmann was using electrons that were naturally ejected from radium bromide. (Goldberg, p. 134)
[11] Such interpretation was premised upon Newton's third law of motion, because it was assumed that the electron was subject to a force that acts in the direction opposite to its motion. (see Jammer, 1961, p. 147)
[12] This postulate was critical, because a non-rigid or deformable electron would require other forces to hold it together, which would constitute a contradiction to Abraham's theory. (Goldberg, pp. 134 – 135)

equations and his attempts to explain the null results of Michelson's experiments. (see Chapter 16) Lorentz's paper also contained his theories concerning electromagnetic mass. Lorentz's theory disagreed with Abraham's in several respects. His formula for the electron's change in mass depended upon his Lorentz transformations and the resulting contraction or deformation of the electron.[13] Consequently, Lorentz's *ad hoc* magnitudes for the electron's longitudinal and transverse mass were somewhat different than Abraham's theoretical magnitudes. (see Chart 31.1) In his April 1904 paper, Lorentz rationalized that his magnitudes for electrodynamic mass agreed with Kaufmann's experimental results "nearly as well as with those of Abraham." (Lorentz, 1904c [Dover, 1952, pp. 30 – 34])

In 1905, Einstein's Special Theory of Relativity was published. In Section 10 thereof, he sought to determine the magnitude of the motion of the electron. First, Einstein determined the equations for the motion and mass of the electron when it was 'at rest' in Lange's moving inertial reference frame. He then transformed such equations with Lorentz transformations and his own transformations for Maxwell's equations, and inquired "as to the 'longitudinal' and the 'transverse' mass of the moving electron?" (Einstein, 1905d [Dover, 1952, pp. 61 – 62]) Thereafter, Einstein derived:

$$\text{Longitudinal mass} = m/(\sqrt{1 - v^2/c^2})^3$$

$$\text{Transverse mass} = m/1 - v^2/c^2$$

(*Id*., p. 63]) It turns out that Einstein's abstract mathematical magnitudes for longitudinal

[13] This effort to remain consistent with the other contraction predictions of his paper resulted in serious problems for his electromagnetic mass theory, which even Poincaré's heroic rationalizations failed to cure. (Goldberg, p. 136)

mass were exactly the same as Lorentz's April 1904 abstract magnitudes.[14] (see Chart 31.1A)

We shall save the discussion and scrutiny of Einstein's concept of Relativistic Mass, and the events that surrounded it, until Chapter 32.[15] The points to be made here are two-fold. First, Einstein utilized the same basic *ad hoc* and arbitrary concepts and methodologies as Kaufmann, Abraham, Poincaré and Lorentz used (which would include ether) in order to arrive at his abstract magnitudes for electromagnetic mass. Second, Einstein premised his concepts of relativistic mass and relativistic dynamics on the *ad hoc* concept of electromagnetic mass (which in reality is <u>not a mass</u> of matter, but only a <u>resistance</u> of the electromagnetic medium), and on Abraham's *ad hoc* and immeasurable concept of longitudinal mass.

In 1906, Poincaré published a paper that attempted to correct and defend several of Lorentz's concepts related to the electromagnetic mass. He theorized that non-electromagnetic forces must be present in order to hold the deformable electron and its charge together and to maintain their mutual repulsion in an infinitesimal space. However, such a theory would appear to contradict the total electromagnetic concept of mass. If Poincaré's theory were accepted, the only way to save the electromagnetic concept of mass would be "to describe the electron as a structureless point charge" with a radius of zero. (Jammer, 2000, p. 36) With this scenario, the energy of the electron's mass would become infinite. Jammer concluded that "classical electromagnetic theory

[14] This should not be considered as amazing, because Lorentz published his magnitudes in April 1904, the year before Einstein's Special Theory paper. On the other hand, Einstein's magnitudes for transverse mass were dramatically different than those of Abraham and Lorentz. (Chart 31.1B)

[15] Einstein applied his Lorentz transformations to the concept of electromagnetic mass in order to describe a variable, velocity-dependent concept of mass ('relativistic mass'). However, this concept of relativistic mass was merely a mathematical generalization of the prior *ad hoc* work of others, and coincidentally its magnitudes only roughly approximate dubious experimental results. Likewise, 'relativistic dynamics' depends upon the validity of relativistic mass and the Lorentz transformations. (see Chapter 31)

has never resolved this problem."[16] (*Id.*) Jammer also concluded that:

> "The early enthusiasm with which the theory was met, however, soon diminished, for it became increasingly clear that the electromagnetic theory of mass was unable to carry out successfully the necessary generalizations for the constituents of matter other than electrons."[17] (Jammer, 1961, p. 152)

D. Feynman's Problems with Electromagnetic Mass

In his 1964 lecture, entitled "Electromagnetic Mass," Feynman applied Special Relativity to Maxwell's equations which resulted in the proposition: that a charged particle in an EM field will have a momentum proportional to its velocity. (Feynman, 1964, pp. 28-1, 28-3) This means that there must be a mass as "the coefficient between momentum and velocity." (*Id.*, p. 28-5)

> "The momentum in the field—the electromagnetic momentum—is proportional to *v*. It is just what we should have for a particle with the mass equal to the coefficient of *v*. We can, therefore, call this coefficient the electromagnetic mass." (*Id.*, p. 28-3)

The energy of the charged particle in the EM field must also be proportional to the velocity, "because in the relativity theory they are different aspects of the same four-vector." (*Id.*, p. 27-1)

However, when "concepts of electromagnetic momentum and energy [are] applied to the electron or any charged particle," difficulties occur. (Feynman, 1964, p. 28-1) Even, "when electromagnetism is joined to quantum mechanics [QED], the difficulties remain." (*Id.*) The difficulties include: 1) "the discrepancy between the two

[16] Often when theorists are forced to come up with impossible solutions in order to save a theory, this means that the theory is wrong. Such was the case with 'ether,' and also with 'electromagnetic mass.'
[17] Nevertheless, vestiges of electromagnetic mass live on in certain concepts, such as Einstein's relativistic mass, $E = mc^2$, quantum mechanics, quantum electrodynamics (QED), quantum field theory, particle physics, superstring theory, and General Relativity.

formulas for the electromagnetic mass"[18] (*Id*., p. 28-4); 2) where does the [electromagnetic] mass come from" (*Id*., p. 28-3); 3) where does the extra force [of resistance] come from" (*Id*., p. 28-7); and 4) how can "the idea of an electron as a simple point charge…be maintained." (*Id*., p. 28-6)

Feynman attempted to solve the paradox of the above difficulties with every conceivable theory, but to no avail. He concluded that "difficulties associated with" Maxwell's classical electromagnetics theory were the cause, and therefore Maxwell's theory needed to be modified. (Feynman, 1964, p. 28-1) He even attempted to modify Maxwell's theory, but again he could not find a solution. (*Id*., pp. 28-6 through 28-12)

The author would like to suggest that perhaps Feynman was looking in the wrong place. In other words, that Einstein's relativistic concepts, which defined Feynman's basic premises, were the culprits. In effect, that: 1) Einstein's concept of electromagnetic (relativistic) mass is not a material mass, but rather is only a theoretical electromagnetic resistance; 2) that electromagnetic (relativistic) momentum, electromagnetic (relativistic) energy (if they do exist), and relativistic mass (which is only a variation of electromagnetic mass) are not proportional to, nor dependant upon, any velocity (see Chapter 31); and 3) that $E = mc^2$ is *inter alia* only a general approximation of convertibility and not a rigorous formula of equivalence. (Chapter 32)

E. Conclusions

Material mass remains an abstract and amorphous concept even though, along with space and time, it should be one of the most fundamental concepts in nature.

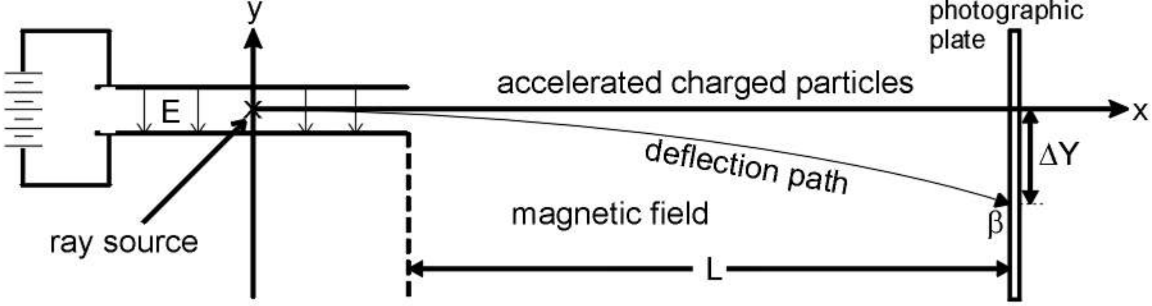
[18] The two theories were the classical theory and Einstein's relativistic theories "that mass depended on velocity" and $E = mc^2$. (Feynman, 1964, p. 28-4) Feynman also premised this discrepancy upon dubious conclusions by Lorentz. (*Id*.)

However, this should not be considered as a revelation, because "the most important and most fruitful concepts are [often] those to which it is impossible to attach a well-established meaning."[19] (Kramers, 1947, p. 196) Jammer concludes:

> "The notion of mass seems to elude all attempts at a fully comprehensive elucidation and a logically as well as scientifically unobjectionable definition…" (Jammer, 1961, pp. 223 – 224)

> "One has to admit that in spite of the concerted effort of physicists and philosophers, mathematicians and logicians, no final clarification of the concept of mass has been reached." (*Id*., p. 224)

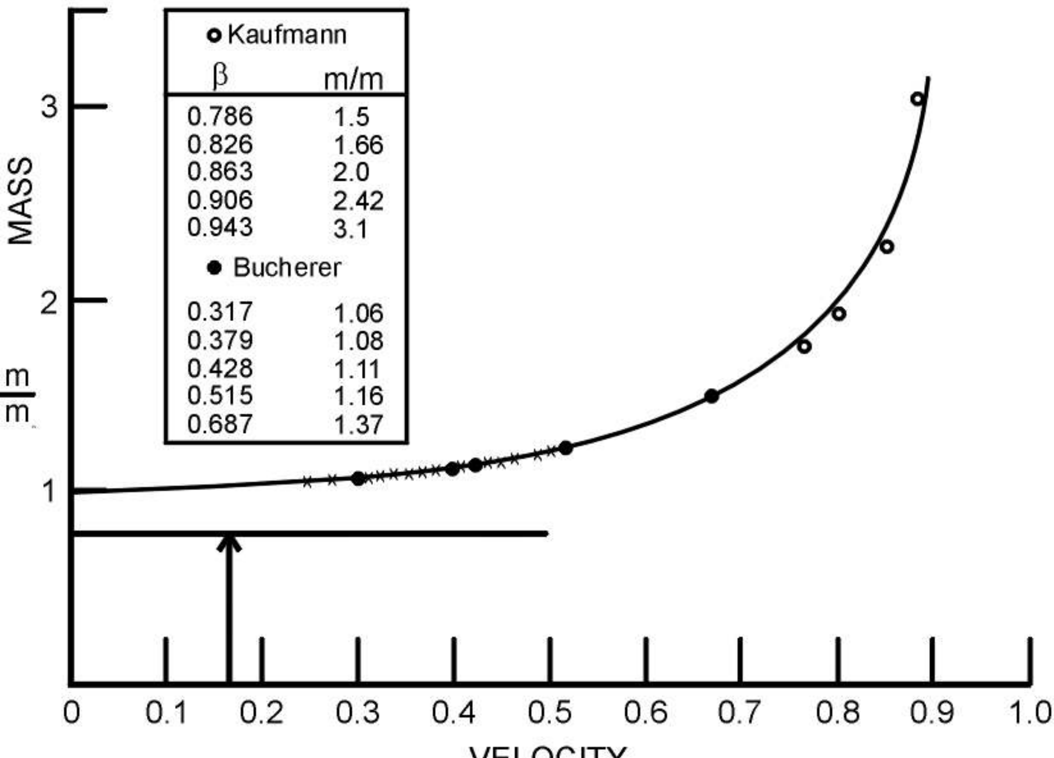
[19] In this regard, consider such concepts as: infinity, eternity, creation of the universe, and creation of life.



Source: Zhang, p. 228

Fig. 317.1A Kaufman's And Bucherer's Experimental Apparatus

The deflection path of a charged particle is nothing more than Faraday's perpendicular force of a magnetic field upon electrically charged moving particles. Angular momentum naturally increases with electromagnetic resistance.



Source: Zhang, p. 227

Fig. 17.1B Interpretations Of An Electron's Mass With Velocity

Figure 17.1 Electromagnetic Mass Experiments