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History of electromagnetic mass

History of charge

Even in ancient times, people distinguished “resinous” and “amber” electricity. The concepts of positive and negative charge were introduced by Benjamin Franklin. The interaction of electric charges was first described by Coulomb's law in 1785.

For a long time, the nature of electrical phenomena was completely incomprehensible, and entities like special “electric fluids” were introduced in order to explain it. In 1801, Johann Ritter advanced the idea of a discrete structure of electricity. In his 1846 investigations, Wilhelm Weber introduced the concept of the electricity atom and the hypothesis that its motion around the material nucleus may explain thermal and light phenomena. Michael Faraday coined the term “ion” to descrribe the carriers of electricity in an electrolyte and suggested that the ion has continuous charge. In 1881, J. Stoney was the first to calculate the charge of a monovalent ion in electrolysis, and, in 1891, he coined the term “electron” to denote the electric charge of a monovalent ion in electrolysis.

In 1881, in a speech devoted to Faraday, Helmholtz expressed his idea of the atomicity of electricity in the following clear form: “If we assume the existence of chemical atoms, then we are forced to conclude that electricity, both positive and negative, is also divided into certain elementary quantities, which play the role of atoms of electricity.” H. Helmholtz showed that Faraday's conception must be consistent with Maxwell's equations.

In 1895, Joseph J. Thomson began to methodically research the deflection of cathode rays (discovered by Julius Plucker) in electric and magnetic fields. Thompson argues that all the particles forming cathode rays are identical to each other and form a part of the substance. During the evening session of the Royal Society on April 29, 1897, Thomson described the essence of his experiments and his hypothesis about the existence of matter in a state of even greater fragmentation than atoms.

In the early 20th century, American physicist Robert Millikan experimentally showed that electric charge is *discrete*. A body’s charge composes an integral multiple of the elementary electric charge. The first experiments in electron investigation showed that the electron behaves not only as a tiny electrical charge, but also as an object with a mass; the electron, in the experiments, displayed the mechanical inertia.

If the electron has a mass, its inertia must appear everywhere, not only in the electric field. In 1913, Russian scientists L.I. Mandelstam and N.D. Papaleksi ran a new experiment.

They took a coil of wire and twisted it in different directions. For example, they spun it clockwise, then abruptly stopped it and spun it counterclockwise. They reasoned that if electrons really have mass, then when the coil stops suddenly, the electrons should continue to move for some time by inertia. The movement of electrons through wire is an electrical current. They were correct. They connected a telephone to the ends of the wire and heard the sound. Since the sound can be heard in the phone, the current must be flowing through it.

Mandelstam and Papaleksi’s experiment was repeated by American scientists Richardn C.Tolman and T. Dale Stewart in 1916. They also spun a coil, but, instead of a telephone, they connected the coil to a charge meter, the ballistic galvanometer. They managed not only to prove the existence of electron mass, but also to measure it. The data of Tolman and Stewart was then tested and refined many times by other scientists, and it is now known that the mass of electron is 9.109 x10^{-31} kg.

Electromagnetic mass

The concept of "electromagnetic mass" was introduced in 1881 by J.J. Thomson, who so named that part of the mass which is specified by the energy of the electrostatic field of the charged particles. This work is considered the first to discuss the relationship between energy and mass. In it, Thomson showed that the energy of the electrostatic field of the electron must be linearly related to its mass. Thomson started from the mechanical perceptions of the ether that prevailed in science until the early 20th century. He calculates the field of a charged sphere moving with some speed, assuming that the electric field is deformed with the acceleration (?!). At the same time, an additional electromagnetic mass of charge appears, which, at low speeds, is equal to $\frac{2\mu e^2}{3a}$, where e is the charge of the sphere in electromagnetic units, a is the radius of the sphere and μ is the magnetic permeability of the medium. When the speed approaches the speed of light, the mass increases to infinity. "In other words," Thompson writes, "the increase of the speed of charged bodies moving through the dielectric to a speed greater than light speed is impossible." The relativistic conclusion about the ultimate value of the speed of light was therefore obtained two years before the birth of Einstein.

Even in his early works, Hendrik A. Lorenz started to introduce atomistics into the theory of electricity. In 1892, he stated the basics of electron theory. The world consists of a substance and ether (in the hypothesis of stationary ether), and Lorenz calls the substance "everything that can be part of electrical currents, electrical displacements and electromagnetic movements…All bodies with weight consist of many positively and negatively charged particles, and electrical phenomena are generated by the displacement of these particles."

Studying the motion of electrons in external fields, Lorentz generalized observations and deduced the force acting on an electron moving at the same time in the electric and magnetic fields, which was subsequently named after him. It has the form $\vec{F} = e \cdot \vec{E} + \frac{e}{c}\left[\vec{v} \times \vec{B}\right]$.

Here e is the particle charge, E is the electric field intensity, B is the magnetic induction, v is the speed of a charged particle with relation to the coordinate system in which the values F, E, and B are calculated, and c is the speed of light in a vacuum. The formula is valid for any values of the velocity of a charged particle.

The first term on the right side of the formula is the force acting on a charged particle in an electric field, while the second term is the same force, but in a magnetic field. The magnetic part of Lorentz's force. is proportional to the vector product of v and B, i.e. it is perpendicular to the particle's velocity and the vector of magnetic induction. Consequently, it does not perform mechanical work; it only curves the trajectory of a particle without changing its energy. According to Lorentz's audacious hypothesis, all molecular forces are electric!

So, it was clear in the early 20th century that:

• tiny carriers of electric charge and mass exist,
• electrical, magnetic and mechanical phenomena are closely related,
• the atoms of substance consist of oppositely charged particles, and
• all the grounds for a correct answer to the question of the essence and nature of inertia, mass, and

Newton's laws were prepared.
However, for a variety of reasons, the question was not answered...

The era of Maxwell-Einstein

Historically, it was Michael Faraday who first introduced the concept of the “field,” which was strengthened by the works of Maxwell. Significantly later, experiments confirming the existence of elementary charge appeared. At first, the concept of the field was only intended as a temporary model, but it became an increasingly real physical entity in the physics of the 19^{th} century. It led to the understanding of many facts already known in the field of electrical and magnetic phenomena and to the prediction of new phenomena. The system which provided the basis for Maxwell's equations was called Maxwell's electromagnetic field theory. A new type of physical reality was proclaimed: a field, which is not reducible to material points or to any substance or to atoms.

Electromagnetic field theory did not manage to solve a set of problems related to the relation of charge, mass, Newtonian laws and the laws of Faraday. In order to resolve the accumulated contradictions, Einstein proposed a mathematical model of physical reality. Einstein pointed out that it is not points of space or time that possess physical reality, but the events themselves that are defined by four numbers x, y, z and t.

The special theory of relativity (STR), based on the consideration of inertial reference systems, allows us to determine an important relationship for accelerated motion. In relativistic physics, it is believed that the higher the velocity of the body’s motion, the harder it is to increase it. Since the resistance to speed change in the velocity of the body is called its mass (inertial), it follows that the mass of the body increases with the increase of velocity of its motion. This is true with one condition: it is tacitly believed, in this reasoning, that the electron is accelerated by a constant force, but this belief has never been seriously tested. In classical mechanics, mass is considered a constant value, which, in relativistic mechanics, is called the “rest mass.” Change in mass can be detected only at high speeds.

Based on the principle of equivalence of gravitational and inertial masses and the dependence of the mass on velocity, Einstein drew a radical conclusion in SRT about the equivalence of mass and energy.

As for the physical reasons for the origin of mass, they remained undiscovered.

Feynman’s search

The question of mass did not leave the minds of scientist, and in 1962 it was raised by Richard F. Feynman.

Feynman suggests that the nature of mass is electromagnetic. The great teacher discusses it as follows:

> Whence did the general concept of mass arise? According to our laws of mechanics, we assume that every subject has some property which is called mass. It means the proportionality of an object’s impulse to its speed. Now, we have found out that this property is quite comprehensible - a charged particle carries impulse, which is proportional to its speed. The case can be presented as if mass is just an electrodynamic effect. Indeed, until now, the reason for the origin of mass remained undisclosed. And then, finally, an opportunity had been put in our way, in electrodynamics, to understand what we never understood before. The explanation of the proportionality of impulse of every charged particle to its speed through the electromagnetic properties dropped as if from the clouds (or rather, from Maxwell and Poynting).

More...

“The Feynman Lectures on Physics”, R. Feynman, R. Leiter, M. Sands, v.6, chapters 28-3

The results of his calculations give, as electromagnetic mass, the expression $m_{em} = \frac{2}{3}\frac{e^2}{ac^2}$, and, correspondingly, for energy $U_{em} = \frac{4}{3} m_{em} c^2$. As you can see, this expression does not coincide with the known formula U = mc^2.

Even before Feynman, in 1958, Sommerfeld obtained his formula for electron rest mass:

$m_0 = \frac{\mu_0 q^2}{6\pi \cdot r_0} [кг]$ (System International).

The discrepancies in the results of these calculations forced R. Feynman to admit that electron mass (and thus the mass of other elementary particles) consists of not only the electromagnetic part, which has a physical nature, but also of some mysterious "mass of non-electromagnetic origin," which has no distinct explanation.

Another issue unresolved by Feynman is the relation of the neutron and proton masses, the two particles which are so similar in terms of strong interactions and different in terms of electric interactions. At the time, the experimental data about the presence of variously charged regions inside the neutron did not exist.

So, the nature of mass was not detected by Feynman. However, his weighty opinion was the reason that further development of the topic was put off for the foreseeable future.

What kinds of mistakes are there in the logic of R. Feynman and A. Sommerfeld? And what else must be "added" to electrodynamics in order to create a unified field theory?

The excellent teacher and great scientist Feynman, when speaking of mass, lost sight of the fact that bodies shows inertial properties only when their velocity is changed (with acceleration). In cases of uniform motion of the body, or at rest, we cannot talk about the demonstration of inertia. At the same time, Feynman and Sommerfeld carried out their calculations considering the field of a uniformly moving electron and basing their work on Lorenz's ideas about the distortion of the field of a moving electron. However, in both Newtonian mechanics and the mechanics of Einstein, as well as in practice, there is no way to ascertain the fact of uniform rectilinear motion of a closed physical system. If the field of a uniformly moving electron really was distorted, it would create the possibility of observing such motion. Accordingly, the field of a uniformly moving charge is not distorted!

Another of Feynman's fundamental mistakes was his use of Poynting's vector to describe the energy transfer by an electron field. Poynting's vector can only be applied to electromagnetic waves. In the case of a moving charge, it is necessary to use Umov vectors, which are associated with convective energy transfer. (The Poynting vector is a special case of the Umov vector). An easy-to-understand explanation of the difference between these devices is given in the works of Maria Korneva and Victor Kuligin (see more details).

Our discovery of the inaccuracies in Feynman's approach and the recent confirmation of Enrico Fermi's hypothesis of a complex structure of the neutron (launched in 1947) returned us to the idea of electromagnetic mass.

We believe that the well-known phenomenon of self-induction is responsible for the inertia of the electron and other elementary particles. According to the definition of electric current, the motion of a charged particle is current. Accelerated (irregular) motion is a time-varying current. Any time-varying current is accompanied, according to M. Faraday, by the phenomenon of self-induction. Self-induction, according to the rule of Lenz, is always directed against the force that caused the change in the current (caused the acceleration of charged particles). This is the force which is accepted as inertia.

Since uncharged matter does not exist, as has been shown in our studies [see articles "The equivalence principle" and "The mass"], all bodies are composed of charges. This leads to the natural conclusion that the inertia of any body, even an electrically neutral one, can be explained by the phenomenon of self-induction. Let us consider this conclusion in more detail.

Let us remember the definition of self-induction.

The electric current in a certain coil produces a magnetic flux, which penetrates this coil. If the current in the coil varies with time, the magnetic flux through the coil will also change, inducing an EMF in it just as it occurs, when the transformer is working. The emergence of the EMF while current is changing in the coil is called self-induction. Self-induction influences the current in the coil. Likewise, the inertia influences the motion of bodies in mechanics; it slows the establishment of direct current in the circuit at power-up and prevents it from instantaneously stopping at shutdown. In an AC circuit, the self-inductance creates a reactance limiting current amplitude.

In the absence of magnetic materials near the motionless coil, the magnetic flux's penetration of it is proportional to the current in the circuit. According to Faraday's law, in this case, the EMF of self-induction should be proportional to the rate of change of the current, as in

$$E = -L \cdot di / dt \ ,$$

where L is the coefficient of proportionality called self-induction or inductance of the circuit. The formula can also be considered the determination of the value L. If the EMF (E) induced in the coil is expressed in volts, current i in amperes and time t in seconds, then L is measured in henry (Hn). The "minus" sign points to the induced EMF opposing increases in the current i, as it follows from the law of Lenz. External EMF overcoming the EMF of self-induction should have a "plus" sign. Therefore, in AC circuits, the voltage drop across an inductance is equal to $L\,di/dt$.

When a body moves with acceleration, all the charges in the body are also moving with acceleration. The charge moving with acceleration is by definition a variable (alternating) current. The alternating current causes the phenomenon of self-induction. The EMF of self-induction obstructs the force that caused the change in current; it obstructs the acceleration of the charge.

The total force of inertia is made up of the forces of self-induction acting on each charged particle of the macrobody individually. The revealed mechanism shows that inertial forces are not fictitious and that they are conditioned by electromagnetic phenomena.

Calculations and conclusions

Now let us consider the second and third laws of Newton, $\vec{F} = m\vec{a}$ and $\vec{F}_1 = -\vec{F}_2$.

By applying force to any body, we are accelerating the body, and we are thus accelerating all micro-charges which form parts of this body. Consequently, each particle of the body becomes the current, notably alternating current. The phenomenon of self-induction emerges, which is described, according to Faraday, through the EMF of induction.

$$E = -L \cdot di / dt$$

Here $L = \frac{\mu_0}{2\pi} r_0$ is the inductance (coefficient of self-induction) of the sphere. In the formula, the minus sign appears according to the rule of Lenz, showing that the EMF is always directed against the forces that caused the change in current.

The EMF of self-induction causes the emergence of electric field $E_i = E / 2r_0$ of self-inductance, and it acts on the charge by the force

$$F = qE_i = -\frac{qL}{2r_0} \cdot di / dt$$

Therefore, it is clear that the force counteracting the acceleration is directly proportional to the current change associated with the charge motion. Now let us express the change in current intensity over the course of time:

$$\frac{di}{dt} = \frac{d}{dt}\frac{qV}{2r_0} = \frac{q}{2r_0}\frac{dV}{dt} = \frac{q}{2r_0} a$$

Consequently, the force that emerges in case of the body's acceleration can be expressed as the following:

$$F = -\frac{qL}{2r_0} \cdot di / dt = -\frac{q}{2r_0 \cdot 2\pi}\mu_0 r_0 \frac{q}{2r_0} a = -\frac{\mu_0}{8\pi}\frac{q^2}{r_0} a$$

Comparing this with Newton's second law

$$F = -ma,$$

we see that particle mass is determined by the expression

$$m = \frac{\mu_0}{8\pi}\frac{q^2}{r_0}$$

We mention here the important fact that the mass derived from the law of self-induction corresponds completely with Einstein's mass $m = \frac{\mathrm{U}}{\mathrm{c}^2}$, if the total energy of the electron U is understood as the self-energy of its electric field.

Correspondingly, both the second and third laws of Newton simply express the properties of electromagnetic induction. Newton's method – development of a model of the phenomenon without inventing hypotheses, and then, if the data are sufficient, the search for the causes of this phenomenon – can be discarded. *The substitution of charge for mass* reveals the mechanism of Newtonian laws and a set of other phenomena.

Now the stability of the orbits of planets in the solar system becomes clear. Since gravity acts on the planets with some forceF_{grav}, and the substance (the planet) resists with the combined power of self-inductionF_{Σ}, provided that F_{Σ}, =- F_{grav} , no forces act wholly on the planets, and therefore planets do not change the nature of their movement.

In the virial theorem, the emerging EMF of self-induction counteracts the centripetal force. Feedback appears. EMF grows until it equals the F_{cp} in magnitude.

Using the laws of electrostatics and the virial theorem, we have calculated the bond in the hydrogen molecule (see more details). The results speak for themselves; the discrepancy between the calculated value of molecular size and the experimental value is less than 4%. Thus, our theory of bonding explains the stability of molecules and atoms. The absence of electron radiation in an atom is a weighty argument for the electromagnetic description of the world.

The spectacular confirmation of the theory of relativity - the phenomenon of electron and positron annihilation - also works for the electromagnetic conception of mass. Thus, in classical mechanics, the charged particle (either electron or positron) has its own mass m, kinetic energy K (if the particle is initially moving) *and* the self-energy of the electric field of the charge $q\phi/2$, where ϕ is the potential of the electric field near the particle. The energy of γ-quanta born as a result of the annihilation of electron-positron pairs is exactly equal to $2 \cdot mc^2 + 2K$.

And where, in this case, is the energy of the electric fields of particles? Where did their Coulomb energy go? This hitherto unresolved question of physics can be easily explained by our theory. In the electromagnetic concept of mass, charge does not have two masses (the non-electromagnetic mass m and the mass of field $q\phi/2c^2$) but one - and this mass is entirely of electrical origin! The energy of the "masses" of particles is the self-energy of their Coulomb fields.

It is enough to look around closely and you will find numerous confirmations of the electromagnetic nature of mass. The method of mass spectrometry is used to determine the mass of elementary particles. It affords an opportunity to measure the ratio of mass to the charge of the particle. What kind of mass do we mean? Inertial. Experience shows that the inertial mass to the 3rd sign is equal to the weight of the particle (see more details). Using the equivalence principle (inertial mass is equal to gravitational mass), we see that there is nothing left for the neutral mass of Feynman. Uncharged particles in crossed electric and magnetic fields do not deviate. This also leads to the conclusions of the unbreakable bond of charge and mass and of the absence of uncharged mass.

So, inertial, electric and gravitational properties of the body are determined by charge but not mass. It is not mass that is the original initial essence of matter, but charge. The replacement of one value with another allows us to get rid of the contradictions in the laws of Newton, in which the inertial properties of the body appear instantly with changes of speed, and the opportunity to impart acceleration to a body exists instantly. In reality, these events occur with some time latency. Such hitches in time lead us to thoughts about the existence of "ether," presumably composed of particles such as positronium (in which an electron and a positron circle a common center of mass). Mass as an independent concept does not exist. Introduced by Newton 300 years ago, it has not received a physical explanation, and, according to the laws of history, it should leave the arena of physical activities.

Another well-known fact: the work of modern power generators and motors proceeds with an efficiency factor close to 100%. This means that, in these devices, most of the energy is expended to overcome the inertia of the charges in the matter, and virtually all the mechanical energy is converted into electricity and vice versa. Consequently, the idea of the electromagnetic nature of mechanical forces finds direct evidence here.

When Faraday first published his remarkable discovery that the change of magnetic flux creates an EMF, he was asked (as everybody is asked who discovers some new phenomena): "What is the benefit of it?" After all, all that he discovered was the emergence of a tiny current in the wire. Faraday replied: "What is the benefit from a newborn baby?" The "fully-grown child" has given us a point of view on electrodynamics from the perspective of the concept of the field. All industry works on that foundation. Faraday's laws explained the mechanism of Newton's laws, the stability of the orbits of the solar system and the physical meaning of the virial theorem.

Thus, gravitational forces, which are difficult to unite with other forces, have ceased to be an obstacle to the creation of a unified field theory. Faraday’s discovery brought us closer to a unified theory of everything.

Newton's mechanical mass dominated science for about 200 years, before individual scientists made the very first attempts to discover the physical mechanism of the phenomenon of inertia and to connect mass with the electromagnetic properties of elementary particles. It took another 100 years of struggle in order for this idea to finally be formed and take its rightful place in modern science.