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ARGUMENTS IN FAVOUR OF ACTION AT A DISTANCE

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Several arguments favouring instantaneous action at a distance are presented. The action at a distance laws of Newton, Coulomb, Ampère and Weber are analysed. Historical evidence that Weber's electrodynamics led to the finite propagation of electromagnetic signals prior to the development of Maxwell's equations are emphasized. The implementation of Mach's principle with Weber's law applied to gravitation is discussed.

1. Introduction

In this paper I present several arguments in favour of action at a distance. But first let me present some personal recollections on this topic.

At high school (1977-79) I learnt Newton's law of gravitation (1687) and didn't see any problems with it. By reading history of science books I discovered that Newton's contemporaries Huygens and Leibniz could not accept his conceptions because they implied that the sun acted directly on the earth, the earth on the moon etc. I remember that I could not understand their negative attitude because to me it was obvious that the sun attracted the earth and that the earth attracted the moon and the apple. At that time I didn't think in any other mechanism that could explain their attraction.

When I was doing my undergraduate course in physics (1980-83) I realized how problematic is Newton's law of gravitation due to its action at a distance character. For instance, how could the sun know from a distance how much mass there is on earth in order to apply the correct force on it? How was this force transmitted from the sun to the earth? Can a body of finite dimensions act on other bodies located in places where the first body is not touching? Then I understood Huygens and Leibniz criticisms. I also began to speculate on other mechanisms for the interaction between bodies, like the exchange of particles (photons or gravitons) at a finite speed, the emission of gravitational and electromagnetic fields at light velocity or perturbations in a continous medium like an aether. I then changed my mind and concluded that there was no action at a distance.

In 1986 and 1987 I began some anotations on what I called General Principles of Physics.

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That is, principles which I believed should be valid in all physics, including mechanics, thermodynamics, optics or electromagnetism.

The first principle was that the laws of physics should depend only on the distances between interacting bodies and their time derivatives. That is, the relevant quantities should not depend on the position, velocity nor acceleration of the observer. All basic laws of physics should be in the form $f(\vec{r}_i - \vec{r}_j, \vec{v}_i - \vec{v}_j, \vec{a}_i - \vec{a}_j, d^3\vec{r}_i/dt^3 - d^3\vec{r}_j/dt^3, ..., m_i - m_j$ or m_i/m_j, $q_i - q_j$ or $q_i/q_j, ...)$. Here $\vec{r}_i$ and $\vec{r}_j$ are the position vectors of particles i and j with masses m_i and charges q_i, $\vec{v}_i - \vec{v}_j = d(\vec{r}_i - \vec{r}_j)/dt$ etc. I arrived at this principle when I discovered that in Lorentz's force $\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$ the velocity $\vec{v}$ was employed as the velocity of the charge relative to the observer and not to the magnet or current carrying wire with which it was interacting. I didn't like this interpretation as it was against my physical intuition and then proposed this principle. To me this $\vec{v}$ should be the velocity between the charge and the magnet or current carrying wire with which it was interacting.

The second principle was that kinematics should be exactly equivalent to dynamics. This was my interpretation of Mach's principle and of his analysis of Newton's bucket experiment. I don't remember when I read for the first time Mach's book The Science of Mechanics, [1], but I rememeber discussing his ideas with some friends from 1986 onwards. When the bucket and the water are at rest relative to the earth, the surface of the water is flat. When both rotate together relative to the earth and distant universe the surface is concave. Newton thought this concavity was due to the rotation of the water relative to absolute space disconnected from any material body like the earth or distant stars. Mach was against this interpretation and believed the effect appeared due to the rotation of the water relative to the distant stars. What would happen if the bucket and water were kept at rest relative to the earth, while the distant universe were rotated relative to the earth in the opposite direction around the axis of the bucket with the same angular velocity as in Newton's original experiment? According to classical mechanics the water should remain flat, while according to Mach's principle the water should rise towards the sides of the vessel as in Newton's original experiment. Mach's relational ideas always seemed more intuitive to me than Newton's absolute ones based on empty space. For this reason I proposed to myself the second principle above.

The third principle (written in June 1988) was that there is no action at a distance. I was then believing that all interactions between any two bodies need to travel at a finite speed. It might be through a perturbation in a continuous medium or through the emission and absorption of particles or fields moving with a finite speed in vacuum. My preferred mechanism for their interaction was the exchange of particles like gravitons.

In two weeks during February 1985 I read for the first time Whittaker's book *A History of the Theories of Aether and Electricity*, [2]. But at that time I did not take notice of Weber's action at a distance law. It was in England during 1988 that I rediscovered Weber's law in Whittaker's book and began to work with it. The reason was that it complied with action and reaction, was directed along the straight line connecting the charges and depended only on $r = |\vec{r}_i - \vec{r}_j|$, dr/dt and d^2r/dt^2. This is what I call a relational force law. This was the most striking feature which differentiated it from Lorentz's force law.

It was also in 1988 that I began to apply a Weber's law to gravitation and implemented quantitatively with it Mach's principle. This is described in my first paper published in 1989, [3]. Despite this success I wrote in the paper: "The greatest limitation of this model is that it is based on an action-at-a-distance theory. As a result, it is not a definitive or final theory but should be valid in systems with slowly varying motions in which time retardation is not a serious factor."

Nowadays I am changing my mind once more, returning to my previous points of view of high school. Although I am not yet completely convinced of action at a distance, I see more and more positive aspects related to it. As most physicists of this century are against action at a distance, I decided to write this paper showing reasonable arguments in its favour in order to balance this one side position. This may help other readers to have a more critical point of view and an open mind on this important topic.

2. Quotations in Favour of Action at a Distance

Here I present some quotations in favour of action at a distance.

Ernst Mach presented some interesting remarks in his book *History and Root of the Principle of the Conservation of Energy*, published originally in 1872. On page 56 of the English translation there are these words, [4]:

> *What facts one will allow to rank as fundamental facts, at which one rests, depends on custom and on history. For the lowest stage of knowledge there is no more sufficient explanation than pressure and impact.*
>
> *The Newtonian theory of gravitation, on its appearance, disturbed almost all investigators of nature because it was founded on an uncommon unintelligibility. People tried to reduce gravitation to pressure and impact. At the present day gravitation no longer disturbs anybody: it has become a* common *unintelligibility.*
>
> *It is well known that action at a distance has caused difficulties to very eminent thinkers. "A body can only act where it is"; therefore there is only pressure and impact, and no action at a distance. But where is a body? Is it only where we touch it? Let us invert the matter: a body is where it acts. A little space is taken for touching, a greater for hearing, and a still greater for seeing. How did it come about that the sense of touch alone dictates to us where a body is? Moreover, contact-action can be regarded as a special case of action at a distance.*

Burniston Brown made some interesting remarks in the Introduction to his book on action-at-a-distance, [5](p. 1):

> *When the author was attempting to write a book on scientific method he was faced, almost immediately, by a serious problem. This was because, to explain scientific method, a clear definition must be made between* facts *and* theories. *The theories are invented to give a causal explanation of the facts. To my surprise, although the word* fact *is used everyday by everybody, no one knew how to define its meaning - scientists, lawyers, philosophers - none knew. Bertrand Russell said that a fact was "something that made a proposition true" - but the*

question is, what is the 'something'? (not to mention what is meant by 'true'). After eighteen months of consideration I decided on:

A fact is an assertion that can be verified.

It was many years later that I realised that action-at-a-distance is not just another theory of the propagation of force like ballistic propagation, or waves in an ether. I decided to make this point in a lecture at Oxford by showing the effect of a magnet on another, suspended, magnet. I then pointed out that observable action occurred at an observable distance, so that if any member of the audience said it was not action-at-a-distance it was he who was making hypotheses. No one attempted to deny it. Why should we not admit that, sometimes, what appears to be happening is happening?

The refusal to accept action-at-a-distance, has led to all the difficulties and tortuous explanations connected with the ether-vortices, waves, twisted space-time, and many others - together with abortive experimental efforts to detect the ether.

The time has now surely come out to cut the Gordian Knot by abolishing all the ethers, abandoning the attribution of physical properties to nothing (like ε_o and μ_o), and rejecting purely mathematical constructions like space-time.

For many other quotes and important discussions I refer the reader to the extremely relevant book of Graneau and Graneau, *Newton Versus Einstein - How Matter Interacts with Matter*, [6]. This great book discusses the two main mechanisms which have been proposed in the history of science to explain the interaction between matter: far-action and contact action.

3. Basic Action at a Distance Force Laws

Here I present the main action at a distance laws which have been proposed in physics. All expressions are in the International System of Units MKSA. For references and quotations from the original works see [7].

The oldest and more important action at a distance force is Newton's law of gravitation (1687). In modern vectorial notation the force exerted by gravitational mass m_{g1} on m_{g2} can written as

$$\vec{F} = -G m_{g1} m_{g2} \frac{\hat{r}}{r^2} , \qquad (1)$$

here $G = 6.67 \times 10^{-11} Nm^2/kg^2$ is the gravitational constant, r is the distance between the particles and $\hat{r}$ is the unit vector pointing along the line connecting them.

One hundred years later Coulomb arrived at the force between electrical charges q_1 and q_2 as

$$\vec{F} = \frac{q_1 q_2}{4\pi\varepsilon_o} \frac{\hat{r}}{r^2} , \qquad (2)$$

where $\varepsilon_o = 8.85 \times 10^{-12}\ C^2 N^{-1} m^{-2}$ is called the permittivity of free space. It is very similar to Newton's law of gravitation.

At the same time Coulomb arrived at the force between two point magnetic poles q_1^{mp} and q_2^{mp} as given by

$$\vec{F} = \frac{\mu_o}{4\pi} q_1^{mp} q_2^{mp} \frac{\hat{r}}{r^2} , \tag{3}$$

where $\mu_o = 4\pi \times 10^{-7} kgmC^{-2}$ is called the vacuum permeability.

Between 1820 and 1826 Ampère arrived at the force between two current elements $I_1 d\vec{\ell}_1$ and $I_2 d\vec{\ell}_2$ as

$$d^2\vec{F} = -\frac{\mu_o}{4\pi} I_1 I_2 \frac{\hat{r}}{r^2} \left[2(d\vec{\ell}_1 \cdot d\vec{\ell}_2) - 3(\hat{r} \cdot d\vec{\ell}_1)(\hat{r} \cdot d\vec{\ell}_2) \right] . \tag{4}$$

By integrating this expression over two closed circuits C_1 and C_2 he arrived at

$$\vec{F} = -\frac{\mu_o}{4\pi} I_1 I_2 \oint_{C_1} \oint_{C_2} \frac{\hat{r}}{r^2} (d\vec{\ell}_1 \cdot d\vec{\ell}_2) . \tag{5}$$

In order to unify the laws of Coulomb, Ampère and Faraday (1831) Weber proposed in 1846 the following force between two charges:

$$\vec{F} = \frac{q_1 q_2}{4\pi\varepsilon_o} \frac{\hat{r}}{r^2} \left(1 - \frac{\dot{r}^2}{2c^2} + \frac{r\,\ddot{r}}{c^2} \right) , \tag{6}$$

where $\dot{r} = dr/dt$, $\ddot{r} = d^2r/dt^2$ and $c = 1/\sqrt{\mu_o \varepsilon_o}$.

All of these expressions have the following basic action at a distance property: If one of the particles is on the sun and the other on the earth, these laws say that if one moves one of the particles, increasing its distance to the other particle, the force on the other will change instantaneously.

4. Arguments in Favour of Action at a Distance

All of these force laws comply with the principle of action and reaction. This means conservation of linear momentum for any system of particles interacting according to these laws. These forces are also along the straight line connecting the particles, which means conservation of angular momentum. They can also be derived from potential energies, which means conservation of energy. These three aspects are very important from a conceptual point of view and also simplify enormously the calculations.

Usually people who are against action at a distance try to explain the interaction between charges by pressure and collisions. That is, each charge should emit corpuscules or fields which will propagate in space at a finite speed and will affect the second charge when reaching it. Nowadays there is the opposite mechanism. That is, by Coulomb's or Newton's long range forces it is possible to explain Rutherford's scattering (which can be considered as analogous to a collision of two billiard balls) without the bodies ever getting in touch with one another.

One of the most appealing arguments in favour of action at a distance is how powerful it can be. Here I show how many things are derived beginning only with Weber's force between point charges, (6). For detailed discussions and references see [7] and [8]. If there is no motion between the charges Coulomb's law is recovered, from which Gauss's law can also be derived. If the dielectric properties of materials are given from experiments, the whole of electrostatics can be derived from Weber's law. When there are charges in motion, like in the interaction between current carrying conductors, Weber's law yields Ampère's force between current elements, which predicts correctly the force between the conductors. It also yields the magnetic circuital law and the law of non-existence of magnetic monopoles. When there are variable currents or mobile current carrying conductors, Weber's force also yields Faraday's law of induction. Below I show how Weber and Kirchhoff derived the propagation of electromagnetic signals propagating at light velocity before Maxwell wrote down his equations. It is amazing that all of these far reaching results can be derived from such a simple law as Weber's force between point charges.

When Weber's law for gravitation and the principle of dynamic equilibrium are combined, Mach's principle is implemented quantitatively, see: [3, 9, 10 and 11]. That is, the inertia of any body is derived due to a gravitational interaction with the distant universe. Inertia here means the inertial mass m_i of the body and others things related to it like the kinetic energy $T = m_i v^2/2$, linear and angular momentum, and the inertial forces ($m_i \vec{a}$, centrifugal and Coriolis's forces). That is, the inertia of a body is its resistance to suffer accelerations relative to the distant material universe. Once more this is obtained with Weber's action at a distance law without time retardation. The precession of the perihelion of the planets is also correctly derived from Weber's law. I consider the quantitative implementation of Mach's principle as the most powerful result ever obtained with Weber's law applied to gravitation.

5. Propagation of Electromagnetic Signals

It is usually stated that the propagation of electromagnetic signals like in antennae prove that action at a distance is wrong. Here I will discuss this topic.

The first thing which should be mentioned is that the electromagnetic quantity $c = 1/\sqrt{\mu_o \varepsilon_o}$ (the ratio of electromagnetic and electrostatics units of charge) was first introduced in physics in Weber's force of 1846, [12]. As a matter of fact he introduced the constant a, which by 1856 he was writing as $a = 4/c$, where Weber's c is the ratio of electrodynamic and electrostatics units of charge. But Weber's $c = 4/a$ is not the present day $c = 1/\sqrt{\mu_o \varepsilon_o}$, but $\sqrt{2}$ this last quantity. The first to measure c were Weber and Kohlrausch in 1856, who found $\sqrt{2}c = 4.39 \times 10^8 m/s$, such that $c = 3.1 \times 10^8 m/s$. This was one of the first quantitative connections between electromagnetism and optics.

But what I want to emphasize here is the work of Kirchhoff who arrived at the telegraphy equation in 1857, working with Weber's action at a distance theory. He has three main papers related directly with this, one of 1850 and two of 1857, all of them have been translated to English: [13, 14 and 15]. Weber's simultaneous and more thorough work was delayed in publication and was published only in 1864. Both worked independently of one another and predicted the existence of periodic modes of oscillation of the electric current propagating at light velocity in a conducting circuit of negligible resistance.

In his first paper of 1857, Kirchhoff considered a conducting circuit of circular cross section which might be open or closed in a generic form. He wrote Ohm's law taking into account the free electricity along the surface of the wire and the induction due to the alteration of the strength of the current in all parts of the wire:

$$\vec{J} = -g\left(\nabla\phi + \frac{\partial\vec{A}}{\partial t}\right) \ , \tag{7}$$

where $\vec{J}$ is the current density, g is the conductivity of the wire, ϕ is the electric potential and $\vec{A}$ the magnetic vector potential. He calculates ϕ integrating the effect of all surface free charges:

$$\phi(x,y,z,t) = \frac{1}{4\pi\varepsilon_o}\int\int\frac{\sigma(x',y',z',t)da'}{|\vec{r}-\vec{r}\,'|} \ . \tag{8}$$

where $\vec{r} = x\hat{x} + y\hat{y} + z\hat{z}$ is the point where the potential is being calculated, t is the time, σ is the free surface charge. After integrating over the whole surface of the wire of length ℓ and radius α he arrived at:

$$\phi(s,t) = \frac{\alpha\sigma(s,t)}{\varepsilon_o}\ln\frac{\ell}{\alpha} \ , \tag{9}$$

where s is a variable distance along the wire from a fixed origin.

The vector potential $\vec{A}$ he obtains from Weber's formula given by

$$\vec{A}(x,y,z,t) = \frac{\mu_o}{4\pi}\int\int\int\left[\vec{J}(x',y',z',t)\cdot(\vec{r}-\vec{r}\,')\right](\vec{r}-\vec{r}\,')\frac{dx'dy'dz'}{|\vec{r}-\vec{r}\,'|^5} \ . \tag{10}$$

Here the integration is through the volume of the wire.

After integrating this expression he arrived at

$$\vec{A}(s,t) = \frac{\mu_o}{2\pi}I(s,t)\ln\frac{\ell}{\alpha}\hat{\alpha} \ , \tag{11}$$

where $I(s,t)$ is the variable current.

Considering that $I = J\pi\alpha^2$ and that $R = \ell/(\pi g\alpha^2)$ is the resistance of the wire, the longitudinal component of Ohm's law could then be written as

$$\frac{\partial\sigma}{\partial s} + \frac{1}{2\pi\alpha}\frac{1}{c^2}\frac{\partial I}{\partial t} = -\frac{\varepsilon_o R}{\alpha\ell\ln(\ell/\alpha)}I \ . \tag{12}$$

In order to relate the two unknowns σ and I Kirchhoff utilized the equation for the conservation of charges which he wrote as

$$\frac{\partial I}{\partial s} = -2\pi\alpha\frac{\partial\sigma}{\partial t} \ . \tag{13}$$

By equating these two relations it is obtained the equation of telegraphy, namely:

$$\frac{\partial^2\xi}{\partial s^2} - \frac{1}{c^2}\frac{\partial^2\xi}{\partial t^2} = \frac{2\pi\varepsilon_o R}{\ell\ln(\ell/\alpha)}\frac{\partial\xi}{\partial t} \ , \tag{14}$$

where ξ can represent I, σ, ϕ or the longitudinal component of $\vec{A}$.

If the resistance is negligible, this equation predicts the propagation of signals along the wire with light velocity.

Although in this derivation the interaction between any two charges is given by Weber's action at a distance law, the collective behaviour of the disturbance propagates at light velocity along the wire. This is somewhat similar to the propagation of sound waves derived by Newton or the propagation of signals along a stretched string obtained by d'Alembert. In all these cases classical newtonian mechanics was employed, without time retardation, without displacement current and without any field propagating at a finite speed. Although the interaction of any two particles in all these cases was of the type action at a distance, the collective behaviour of the signal or disturbance did travel at a finite speed.

In these cases there is a many body system (molecules in the air, molecules in the string or charges in the wire) in which the particles had inertia. Is it possible to derive the propagation of electromagnetic signals in vacuum, like in radio communication, by an action at a distance theory? I believe the answer to this question is positive. In practice there is never only a two body system. In any antenna there are many charged particles. Even if the material medium between two antennae is removed, there is always a gas of photons in the space between them. The action at a distance between the charges in both antennae with one another and with the gas of photons in the intervening space may give rise to a collective behaviour which is called electromagnetic radiation propagating at light velocity. Moreover, by Mach's principle the distant universe must always be taken into account. After all, the inertial properties of any charge is due to its gravitational interaction with the distant matter in the cosmos. At the moment I am working on this topic of antennae with Weber's electrodynamics. I am extending Kirchhoff's analysis to consider the case of waveguides, coaxial cables, dipole antennae and other situations dealing with open mechanical electromagnetic circuits.

It should be stressed that the works of Weber and Kirchhoff in 1856-57 were published before Maxwell wrote down his equations in 1861-64. When Maxwell introduced the displacement current $(1/c^2)\partial\vec{E}/\partial t$ he was utilizing Weber's constant c. He was also aware of Weber and Kohlrausch's measurement that c had the same value as light velocity. He also knew Weber and Kirchhoff's derivation of the telegraphy equation yielding the propagation of electromagnetic signals at light velocity.

6. Problems with Contact Action

Beyond presenting positive aspects of action at a distance, I discuss here some problems with contact action. By this term I mean all kinds of mechanism which have been proposed to explain the action between bodies without instantaneous action at a distance. It might be by the exchange of particles (virtual photons and gravitons), by the propagation of continuous electromagnetic and gravitational fields, by the disturbance of an aether, by retarded action at a distance etc.

In classical electromagnetism there is usually Liénard-Wiechert potentials based on time retardation. Problems with this approach have been pointed out by Chubykalo and Smirnov-Rueda [16, 17 and 18] and by Whitney [19 and 20].

It is usually thought that gravity propagates at light speed. However, in a very interesting article discussing this topic, Van Flandern has shown that this velocity has never been directly observed and that many arguments and measurements indicate that if it is finite, then it should be many orders of magnitude larger than c, [21]. In particular, there is no aberration for gravitation. In this connection I should also point out Pope and Osborne discussion of action at a distance related to gravitation and inertia, [22].

It pleases the mind of many people (although not myself) to speak of mechanisms of interactions between bodies as due to an exchange of particles or fields, to speak of connections between the bodies (like through an aether) etc. I myself cannot form mental pictures of these abstract fields or entities. There are also other problems. If a bar magnet moves relative to the laboratory with a constant velocity of 1 m/s, does its magnetic field move with this velocity? Or does it move with light velocity? Or it does not move at all, but only generates an electric field which is also stationary relative to the earth? The same questions might be applied to the electric and magnetic fields due to a point charge moving relative to the laboratory.

How can something immaterial like an electromagnetic field interact with the material charges? People who dislike action at a distance prefer to think in terms of pressure and contact action. For this reason they postulate that each charge emits small particles (like virtual photons or other corpuscules) or a continuous electromagnetic field which will interact with the other charge when reaching it. But they do not specify how this interaction between these small particles (or fields) and the second charge will take place.

Beyond these facts another very relevant one is to dispense with what is not observed. This is a simple rule in physics which has always been forgotten. As the electromagnetic fields, the virtual photons, the gravitons, the ether and other thought entities, are not seen directly, their use in physics should be avoided. What is seen is the motion of material particles like the apple approaching the earth, a magnet influencing another magnet etc. As there are theories like Newton's or Weber's ones which deal only with these observable entities, these theories should be preferred instead of others which employ unempirical conceptions.

I will list here some thought entities which have been postulated to explain gravitation (a similar list can be made for electromagnetic interactions). (I) Descartes thought in 1644 it was due to a vortex of subtle matter circulating around the north-south axis of the earth. Huygens follows this approach but assumes the small particles circulate around the earth in all directions and not only about an axis. (II) Newton himself speculated in another mechanism, as he presented in Query 21 of the *Opticks*: gravity might be due to a medium filling all space, changing its density as a function of the distance to the center of the bodies (rarer within the bodies and denser away from them), with the bodies endeavouring to go from the denser parts towards the rarer due to the elastic force of this medium, [23] (pp.350-352). Newton's medium was essentially stationary and did not circulate around the bodies. (III) One hundred years later Le Sage proposed a different idea: all space was filled with minute particles moving with great speeds in all directions. Two large bodies set opposite to one another would screen each other from bombardment by the corpuscles (as if creating shadows for light). Each body would receive fewer impacts on the side facing the other than on the reverse side. As a consequence, they would move towards one another as if acted by a force falling as $1/r^2$. (IV) At the end of last century, after the works of Faraday and Maxwell based on fields, people began to speak in a continuous gravitational field generated by the bodies and propagating at a finite speed in space. A test body would not interact directly with the other bodies, but only with the local field where it is located, field emitted by the other bodies. (V) Instead of this continuous field, sometimes people think that each body emits gravitons at a finite speed (usually considered to be at light velocity). When these gravitons collide with the other bodies, these bodies move towards the emitting one. (VI) After 1916 with Einstein's general theory of relativity another original thought entity has been proposed: curved-space. According to Einstein, a body does not emit flying bullets, but curves the space around it. A test body moves towards the first not due to a direct and distant interaction, but due to the local curvature of space.

Many other thought entities to explain gravity might be listed here, but these six examples are enough to illustrate the matter. Instead of postulating all these concepts (Descartes's vortex, Newton's ether, Le Sage's corpuscles, Einstein's curved space etc.) it is much simpler to consider only what is really observed: the earth, the apple and the distance between them. Newton's law of gravitation deals only with these quantities and explain the observed facts. For this reason it should be preferred.

I now consider magnetism. The magnetic phenomena are usually explained in terms of a magnetic field $\vec{B}$. This magnetic field is obtained by the right hand rule. Two examples: (A) If there is a circular circuit in the xy plane, centered on the origin, with a clockwise current, the magnetic field at the center will point along the negative z direction. (B) If there is a straight circuit along the z axis with the current flowing along the positive z direction, the magnetic field at any point outside the z axis will point along the poloidal $\hat{\varphi}$ direction, in planes orthogonal to z. These two examples violate Leibniz's principle of sufficient reason (there is a reason for everything that happens, or: nothing happens without a reason why it should be so and not otherwise) or the principle of symmetry: (A) As the current is in the xy plane, all the effects in this plane must be on it, the magnetic field has no reason to choose the negative instead of the positive z direction, for this reason it cannot make this choice; (B) Any point outside the z axis forms a plane with the current along the z direction, such that the magnetic field, the magnetic force or any other physical entity at this point must be in the plane, as there is no reason why it should choose the positive $\hat{\varphi}$ direction instead of the negative $\hat{\varphi}$ direction. As there is no reason why the magnetic field should choose the right hand rule instead of the left hand rule, it cannot make the choice. This means that the magnetic field described in all electromagnetic books should not exist. This shows how problematic is the magnetic field concept from a philosophical point of view.

It should be observed that in Lorentz's magnetic force acting on a point charge or on a current element there is a double vectorial product (or that to obtain the magnetic force the right hand rule is utilized twice): Once in $q\vec{v} \times \vec{B}$ or in $Id\vec{\ell} \times \vec{B}$, and another time to calculate $\vec{B}$. For this reason Lorent'z magnetic force is not so problematic as the magnetic field itself.

But then people will argue that this magnetic field is shown by experiments with magnets (as in Oersted's experiment) or with iron fillings. But all these experiments can be explained by Ampère's action at a distance central force, Eq. (4), without the necessity of speaking in magnetic fields circulating around a current carrying circuit. This has always been the point of view of Ampère himself. Here I quote from his main work *On the Mathematical Theory of Electrodynamic Phenomena, Experimentally Deduced*, [24]:

> *p. 155: The new era in the history of science marked by the works of Newton, is not only the age of man's most important discovery in the causes of natural*

phenomena, it is also the age in which the human spirit has opened a new highway into the sciences which have natural phenomena as their object of study.

Until Newton, the causes of natural phenomena had been sought almost exclusively in the impulsions of an unknown fluid which entrained particles of materials in the same direction as its own particles; wherever rotational motion occurred, a vortex in the same direction was imagined.

Newton taught us that motion of this kind, like all motions in nature, must be reducible by calculation to forces acting between two material particles along the straight line between them such that the action of one upon the other is equal and opposite to that which the latter has upon the former and, consequently, assuming the two particles to be permanently associated, that no motion whatsoever can result from their interaction. (...)

pp. 156-7: (...) It does not appear that this approach, the only one which can lead to results which are free of all hypothesis, is preferred by physicists in the rest of Europe like it is by Frenchmen; the famous scientist [Oersted] who first saw the poles of a magnet transported by the action of a conductor in directions perpendicular to those of the wire, concluded that electrical matter revolved about it and pushed the poles along with it, just as Descartes made "the matter of his vortices" revolve in the direction of planetary revolution. Guided by Newtonian philosophy, I have reduced the phenomenon observed by M. Oerstedt, as has been done for all similar natural phenomena, to forces acting along a straight line joining the two particles between which the actions are exerted (...)

7. Conclusion

My conclusion is that there are many positive aspects related to action at a distance: its simplicity, the powerful results which are obtained with it in electromagnetism and gravitation, the implementation of Mach's principle, the fact that the first wave equation describing the propagation of electromagnetic disturbances was obtained with action at a distance laws prior to Maxwell etc. There are also many problems with contact action based on fields, aethers and ballistic theories.

For these reasons I am becoming more and more sympathetic to action at a distance.

Acknowledgments

This paper is dedicated to Peter Graneau, the strongest advocate of action at a distance known to me. I have profited greatly from many conversations held with him.

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