Radio waves : precursors of the theory of relativity

written by Jean-Pierre Bourdier, helped by his grandson, Samuel L.Mathews. Thank you, Sam !

fig 0
Heinrich Hertz proved experimentally in 1887 the existence of radio waves, forecast in 1873 by James Maxwell's equations.
When a student asked him about the ramifications of his discoveries, Hertz replied : *"Nothing, I guess !"*.....

Great discoveries are often collective works, gradually emerging from an appropriate context , because existing theories do not explain more recent experiments. A textbook case is the theory of relativity, *"crystallization of electromagnetic theory"* in the words of Einstein. It upset over 2000 years of geometry and questioned the works of Galileo and Newton. But do we remember that radio, i.e. electromagnetic waves, is the source of the theory of relativity ?
This article traces the genesis of the relativity theory. A play in 4 acts:
- Act I: the eighteenth century, a stable universe, at Euclid, Galileo, Newton’s orders
- Act II: the nineteenth century, the arrival of troublemakers (electromagnetism, radio waves)
- Act III: early twentieth century, a scientific revolution abolishes the absolutism of time
- Act IV: throughout the twentieth century, the new order triumphs, no experience disabling it

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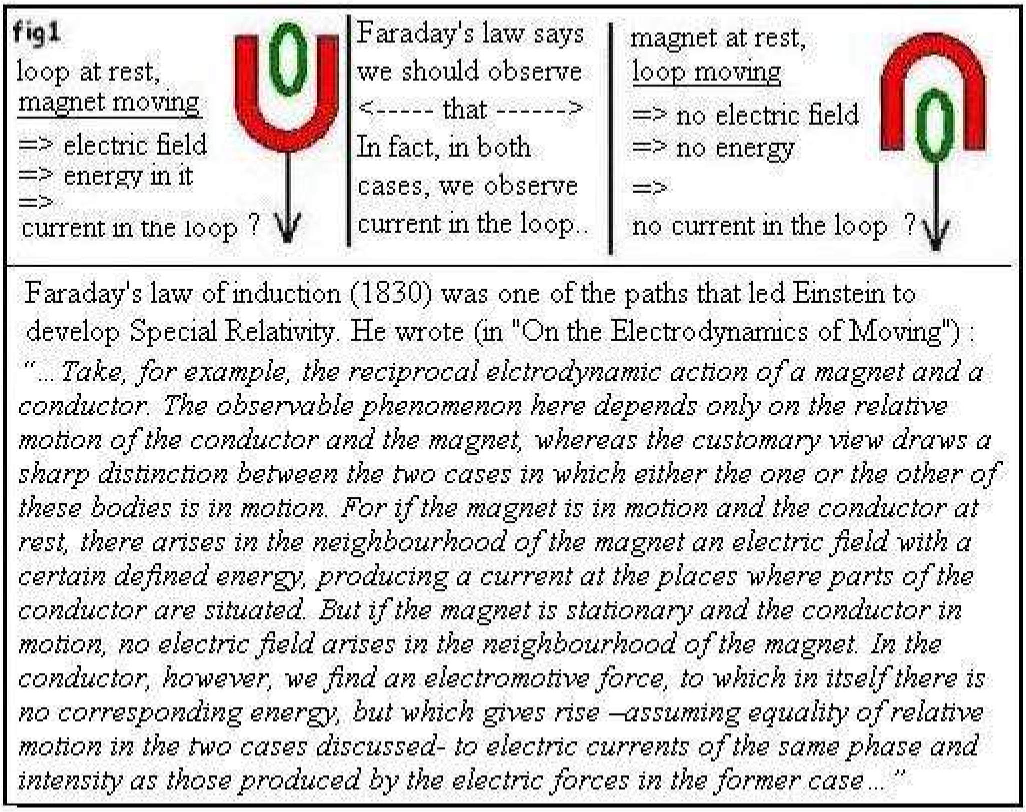
Act I:
In the eighteenth century, a stable universe, at Euclid, Galileo, Newton’s orders

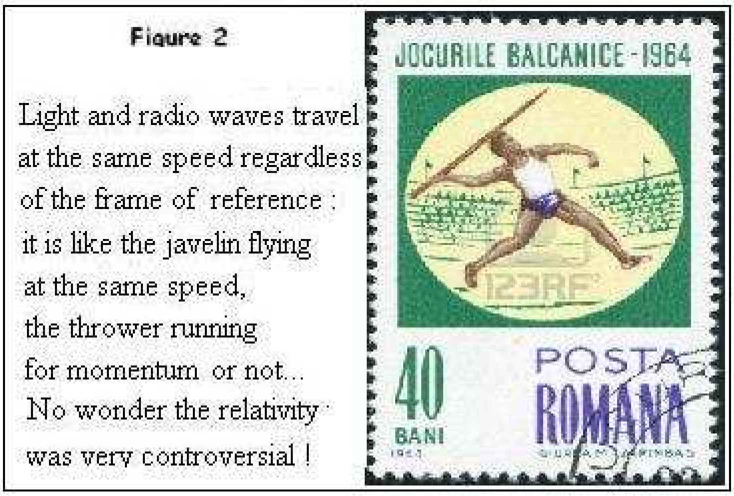
At that time, physics is especially the mechanics of solid bodies, itself derived from antic Greek geometry, and especially from Euclid’s, that so well defined concepts and assumptions describing the world (geo : Earth; metry : measurement). For example, all pupils learn that through a point passes only one parallel to a line ; no doubt (yet ...) about that.
Galileo, sixteen centuries later, appears rightly as the founding father of modern physics, especially in regard to the kinematics (science of movement). He explains how to mark in the 3-dimensional space (latitude, longitude, altitude, for example), discovers a true measure of time : the law of pendulum oscillation (by observing the movement of chandeliers on the ceiling of the Cathedral of Pisa, and correlating them with the beating of his heart ...), sets out a fundamental law in a given reference, a body under no force moves in a straight line at constant speed (known as Galilean reference system).
Newton, a century later, states the law of universal gravitation : the universe is made of fixed stars, one of them (the Sun) has a retinue of planets revolving around it in elliptical orbits ; this movement is fully defined by gravitation (attraction of each planet from the Sun, in proportion to its mass and the inverse square of distance). Earth, in turn, attracts the apple from the tree by the same mechanism.
All this happens according to a non-spatial variable (called “time”) ; its real nature is not clear, but everybody assumes it is something absolute (that is to say, unique and ruling over the universe).

Act II:
In the 19th century, the arrival of troublemakers, electromagnetism and radio waves

The nineteenth century was that of the industrial revolution, made possible by new sources of energy able to replace human and animal muscle work. Thermodynamics (originally from steam engines) and electromagnetism (the source of electric motors) provided both, but there was a catch in the second : it broke the laws of classical mechanics. A famous example of this "disobedience" is due to Faraday, to whom we owe the powerful concept of vector field (see fig.1).



A little later, around 1840, Fizeau who, himself, while working on light (without knowing that it is a wave of electromagnetic nature), made the first measurement of its speed to within 5% and discovered that in circulating water, light moves at a speed that does not respect Galileo and Newton's law of addition of speeds.
Finally, the "ultimate resistance" occurs when Maxwell and Hertz, in 1873 and 1887 respectively, discover electromagnetic waves, the first mathematically by his famous equations, the second experimentally. These waves propagate at light speed regardless of the reference frame, which is contrary to the mechanics of Galileo and Newton. This was disturbing but consistent with what Michelson and Morley's set of famous experiments (1881-1887) concluded. While searching for the invisible, so-called "ether", they realized it did not exist. But they did reveal something much more important : electromagnetic waves, light being one of them, move at the same speed regardless of the chosen frame of reference (something unacceptable under the laws of classical mechanics. It's a bit like a javelin (see fig. 2) flying at the same speed, whether the thrower runs to gain momentum or not; something unimaginable.

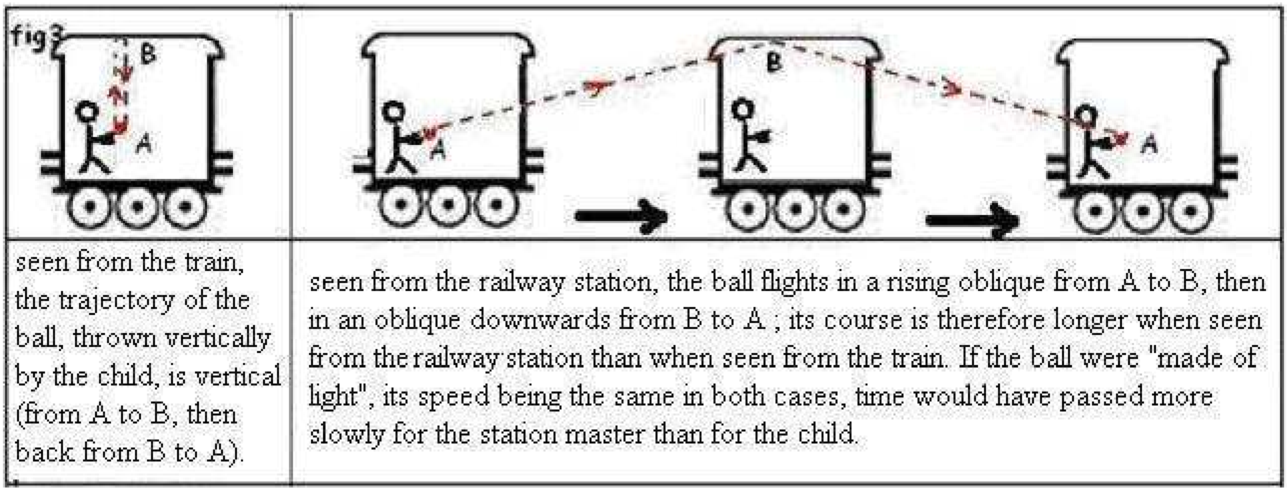


A dilemma arose for scholars at the turn of the 19th and 20th centuries: first the laws of Euclid, Galileo and Newton had proven their great efficiency ; their truth could therefore not be questioned. On the other hand, the laws of electromagnetism had an already large application , it was unthinkable to reject them either. How to cope?

Act III:
Early 20th century, the scientific revolution abolishes the absolutism of time

In science, invention is rarely done by a single person, even if posterity often retains only one name. Thus, the theory of relativity is nowadays usually attributed to Einstein alone, although scientists like Lorentz and Poincaré set before him its basic formulas (at least with regard to special relativity ; general relativity was actually the Einstein’s creation, with the support of his friend Grossmann and Hilbert, two great mathematicians). Nevertheless, Einstein knew better than anyone, and made special relativity a masterful and clearly understood synthesis from its first publication in 1905.

Let's talk first of Special Relativity, which concerns only Galilean reference systems, that is to say in uniform rectilinear translation with each other and try to do it without math. Imagine a child still in a train travelling at constant speed through a railway station (see fig. 3).



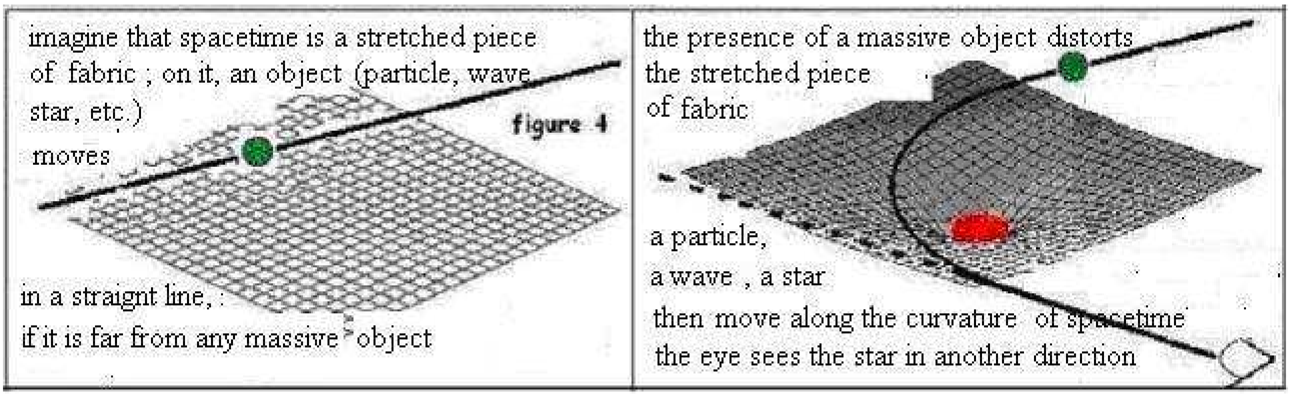
The station master observes the child and sees all his actions (assuming the train has transparent walls). The child is playing ball : he throws his ball vertically, the ball bounces off the ceiling of the car and the child catches it again. We neglect gravity. The trajectory of the ball is different as seen by:
- the child : the trajectory is vertical, composed of two line segments, round trip
- the station master : the trajectory is composed of two oblique segments, one up, the other down:
The ball travels a longer path when observed by the station master than observed by the child
If the ball were light (a photon instead of a ball ...), it would have the same speed in both cases, which means that its return to the child would take longer as seen by the station master than by the child, i.e., time is not the same for the child and the station master. Pythagoras lovers will easily find from this example the formula relating the two times (for a simple demonstration of the general formulas, see bibliography 3).

From those simple formulas, Poincaré, Lorentz and Einstein concluded the following ideas:
- Time is not absolute (it runs faster for the station master than for the child)
- Length is not absolute (seen by the child the car is shorter than seen by the station master)
- Energy and mass are essentially identical : two sides of a "same thing" (the famous formula E = mc2)
- Speed of light in a vacuum is unreachable by object with mass. If the speed of an object approaches the speed of light, its kinetic energy approaches infinity, its length approaches zero, its time tends to stop flowing (let us be cautious when the media announce that faster than light neutrinos have been observed ... before discovering measurement errors : faulty meters, badly connected cables… All radioamateurs experienced such bad experiences, however without challenging Einstein !)
- At speeds much smaller than light (all the "speeds of everyday life"), the above effects become negligible, and the mechanical laws of Euclid, Galileo and Newton are sufficient (classical mechanics is therefore a special case of relativity mechanics).

Let's talk now of General Relativity, which was the subject of Einstein's first publication in 1915. He later explained that not going beyond uniform, linear movement (i.e. without acceleration) was frustrating for him because the universe is mostly made of forces, beginning with gravitation. He therefore took the same premise: a physical phenomenon must be expressed similarly in all reference frames (this is called "covariance of physical laws" with the so-called reference frames).

But when it comes to acceleration or forces, the problem is much more complicated because the mathematical tools that need to be implemented are no longer limited to equations of the first degree (it took ten years of hard work for Einstein, with the help of the greatest mathematicians, to formulate the laws of general relativity). In particular, vector calculus gave way to the tensor calculus (well known in science in civil engineering: soil mechanics, structures beams, deformable structures, etc..), Euclid's geometry must gave way to Riemann's, etc.. (For details on the mathematical aspects of General Relativity, please see bibliography 3).

Let us just give the main consequences of the formulas of Relativity:
- Time is not only non-absolute, but it is totally intertwined with space, so much so that according to Einstein, we can no longer talk in terms of "time and space," even though it is still related to in Special Relativity, but it should be done in terms of "space-time continuum". Note that the latter term has been so overused by science fiction that it has gradually lost the very precise sense given by Einstein, and now we generally prefer to speak of space-time (or universe, but remember that this includes time and space).
- Space-time is "populated" by massless radiation (light, electromagnetic waves, so-called “dark energy”, etc..) and by objects with mass (stars, fermions, so-called “dark matter”, etc..), which all are forms of energy since "mass = energy”.
- Radiation and masses distort space-time (like a mass placed on a fabric (see fig.4) ; in particular, time flows more slowly near a massive star, and the universe we observe is not the same age everywhere (it’s a beautiful subject of meditation, isn’t it ?)



- Gravity is not a force at a distance (Newtonian theory), but a distortion of space-time, which curves the trajectories of objects with mass and radiation (they follow geodesics, like the water following the line of greatest slope of the valley). Again, remember the curvature terms of space and time ...
- The deformation of space-time by objects therein results in a kind of "generalized plasticity of reference systems". Einstein described this by saying that we must no longer think in terms of rigid markers (axes abscissa, ordinate, etc..), but in terms of "mollusk of reference." And he will talk about his mollusk on multiple occasions in his writings and lectures; Einstein was a real genius, able to speak simply of complex things ... This will be criticized by colleagues (alas, nothing has changed…).
- If the stars bend more space-time trajectories of light rays the more massive they are, then one can imagine that some stars are so heavy that nothing can escape, not even the light. The concept of true invisible cosmic sinkholes or" black holes " was born
- General Relativity reduces to Special Relativity or even Newtonian Mechanics in some of the less curved space-time (we found the same nesting between Classical Mechanics and Special Relativity)
- If the universe is curved, an unexpected cosmological problem arises : “is in fact the universe finite or infinite (in space and in time), and does it expand, contract, or is it stable? "

Act IV:
Throughout the 20th century, the new order triumphs : no experience invalidates the theory of relativity

Relativity aroused misunderstandings and laughter until 1960 for several reasons, Special Relativity because it said “time is not absolute” : if the station master had his twin on the train, both twins would not grow old at the same speed (famous paradox so-called the “Langevin twin paradox”, and popularized by the wonderful movies "Planet of the Apes"). General Relativity because of the very abstract mathematical level it requires (remember that Einstein himself had to get help) and the oddity of "space-time continuum like a mollusk in which the light wraps around the stars" ... Note that the theory of relativity, although revolutionary, did not give rise to any Nobel (obtained by Einstein in 1921 but for the photoelectric effect).

Einstein was aware of the very abstract and fragile aspects of his theory, since he wrote himself that “only one little experiment could be enough to disprove the whole theory” ... But now, all accumulated experiences into the second half of the twentieth century did confirm the theory. Let us mention some of them:
- “Time is not absolute” has become a daily experience : we can observe, in cosmic rays or in accelerators, particles "flying almost at the speed of light," and the fact that they live longer “flying than at rest” allows us to see them
- Maxwell's equations, the Faraday law of induction, expressed in terms of relativity covariance, make it clear that the magnetic field and electric field are only "the same concept" (see bibliography 3)
- Mass-energy equivalence was proved "militarily" in 1945 in Hiroshima and Nagasaki, and every day "civilly" in the 440 nuclear reactors generating electric power for homes and industries worldwide
- The bending of light rays by gravity around the sun was observed for the first time during the eclipse of May 29, 1919, which confirmed the theory of relativity. It was reconfirmed several times afterwards.
- The exact trajectory of Mercury, that Newton's law could not fully explain, was finally explained clearly by using the equations of General Relativity
- The bright lines of the spectra of stars are redshifted according to the mass of those stars. These lines are actually the beating of the clocks that are the atoms (this means that the proper time of these atoms is slowed by the mass of the stars)
- The first black holes were observed in the 1960s, and there are now an estimated 100 million of them in our galaxy alone (the Milky Way)
- GPS, commonplace tool in our cars, APRS (appreciated by so many modern OM) exist only because the trajectories of the satellites are calculated from the equations of General Relativity, since the laws of Galileo and Newton are insufficient in this case (see fig.5).

figure 5
Satellite systems for navigation aid (GPS, GALILEO) are using the theory of General Relativity. To achieve sufficient accuracy, the trajectories of satellites and the transmission times are calculated taking into account the curvature of spacetime due to Earth gravitational field.

- Cosmology, since 1915 has finally made great strides, inconceivable without General Relativity: galaxies and clusters of galaxies, big bang, expanding universe, quasars, pulsars, neutron stars, etc.. .

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Einstein wrote *"Relativity is the crystallization of the electromagnetic theory"*. The relationship between radio waves and Relativity is unambiguous. Moreover, we note that although both are already a hundred years old, they are unfortunately neither one nor the other taught before University. You could also say the same thing about other modern disciplines. Basically, this collective ignorance in the face of recent (?) scientific knowledge maybe explains the lack of consideration that our societies have developed for scientific research? Does it not also explain irrational fears of some of the public vis-à-vis things it does not understand, and that condition yet its daily ?

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2 – About Henri Poincaré’s input into relativity, an article of Christian Marchal, Professor of astronomical mechanics at Paris observatory « *Henri Poincaré : une contribution décisive à la relativité* » http://annales.org/archives/x/poincare7.html
3 – Much more modestly, some articles on my radio website **http://f6fqx.chez-alice.fr/**