The philosophy of physics of an engineer

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Abstract. The philosophy of physics of Galileo Ferraris is described through an analysis of his published writings. His philosophical position recalls, for many aspects, that of Hertz. However, the ontological commitment of the two authors is radically different: the ether centered image of the world of Ferraris is contrasted by the much more cautious stand of Hertz.

Contents

1 Introduction

The various aspects of the personality of Galileo Ferraris have been already pointed out and, at least partially, studied. One of the less known features is Ferraris' philosophy of physics: no one of his papers deals explicitly with philosophical or methodological problems; however, his philosophy of physics emerges rather clearly from the network of his writings.[1] Obviously, our reconstruction presents in a systematic way a view whose components are dispersed in many writings: however, the substantial coherence of these components allows such a kind of presentation.

2 Physics as a description of phenomena

Let us begin with the analysis of a rather abstract writing, published after Ferraris' death and attributed to the 1894 - 95 years. These pages, published under the title 'Geometrical theory of vectorial fields', should have been the introductory mathematical part of a textbook on the applications of electromagnetic phenomena [2]. The problem of the physical meaning of the 'fields' is discussed in a systematic way. The fact that this issue is dealt with in a mathematical introductory part is highly significant: it shows how basic was, for Ferraris, the philosophical commitment. The fundamental issue is stated very clearly: if we consider the masses (or the charges, or any other similar theoretical entity) as the sources of the fields, then the fields are produced by masses through an 'action at a distance'; on the contrary, if we consider the fields as the fundamental and primitive theoretical entities, then the masses (and the charges, etc.) are subordinate concepts:

> If in a physics issue we must consider the field of a vector $\vec{A}$, one may ask *where is the place of the elementary phenomena that give rise to the existence of the vector* [...] And the answer to this question, when possible, has a fundamental relevance to physics. In fact, if one maintains that the cause of vector $\vec{A}$ in points P lies in points m, we are led to think of something, of some matter, or of the state of the matter existing in these points [m], of an agent that performs in points P, at distance, actions that can be defined by the vectors $\vec{A}$. Instead, if one holds that the instant cause of vector $\vec{A}$ lies in point P where $\vec{A}$ is observed, we do not have to consider actions at a distance, but we are led to think of a medium that fills all the space and to consider $\vec{A}$ as a manifestation of a state of this medium, for instance of a special deformation of it, deformation that goes continuously from point to point, through infinitely small steps. The most convenient way of describing the field and of treating its equations follows naturally from the choice between the two interpretations. In fact, in the former case, i.e. when one considers an agent located in points m and performing actions at a distance, the quantities m [point masses] and ρ [mass densities], that appear in ours equations, must be considered as fundamental; then, it is consistent with the nature of things to consider these quantities as given and express the other quantities - among them the $\vec{A}$ - as a function of these quantities. In the latter case instead, when one does not consider actions at a distance,

[1] This paper is a development of a previous study that can be found in reference [1].

> the quantity that must be treated as principal, as fundamental, is the $\vec{A}$ itself; the other quantities - and among them the m - appear as secondary.
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> [...]
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> Given the existence of the field, its distribution can be described in various ways. One of them consists in giving directly the vector $\vec{A}$ as a function of the coordinates of the points of the field [...] another way consists in giving as a function of the coordinates not the vector $\vec{A}$ directly, but the $div\, \vec{A}$, accompanied by other conditions sufficient for the complete definition of the distribution [of the field][2] [...] The two procedures are equivalent to two different choices of the quantities that are assumed as given or as unknown in a system of equations: they are equally legitimate and are equivalent; to choose one or the other does not mean to solve any physical issue [3].

Ferraris comes back to the subject in the last pages:

> Between the two ways of defining and treating the field of a vector, which is the best? [...] The answer to this question has been already given. If we consider the vector as a simple geometrical entity, both methods, both fictions, are equally legitimate [...] If, instead, we consider the vector as representing a physical quantity [...] the experimental facts concerning the existence of the vectorial quantity and its distribution are not sufficient to decide which of the two ways of treating the field corresponds better to the physical nature of phenomena. Other experimental facts are necessary to settle this question, for instance, facts showing an influence on the vector intensity by material media filling the field, or facts concerning the way by which the variations of the vectorial quantity propagate in space and time. Until facts of this kind cannot be drawn into the picture, the choice between the two ways is arbitrary and can be made with the only criterion of convenience and clarity [4].

Physics aims at describing phenomena through theories expressed in mathematical language; their predictions must be in agreement with experiment:

> The more abstract, the more probable is a theory. If a theory consists in equations corresponding to facts given directly by experience, it is all that we can today desire. The progress will consists in doing that equations will embrace tomorrow a greater number of experimental facts [5].

Theories are not required to describe exactly how things are and behave in the world:

> Maxwell's equations, or those of Hertz, summarize that part of our notions about the electromagnetic medium that, up to now, in the present state of science, is reducible to a precise form; they summarize what effectively is known from experience about the mechanical properties of the medium. If we know those equations, we are allowed to say that we know the ether, as we say that we know the properties of elastic bodies because we know the equations that rule their equilibrium and motion. A mechanical theory of

[2] Ferraris is here discussing cases in which $rot\, \vec{A} = 0$.

> the ether may be allowed, if it is in agreement with those equations; but, it cannot add nothing to what those equations say, and, if it adds something, it adds too much. Maxwell's or Hertz's equations constitute on their own a mechanical theory, a soft mechanical theory, without a specific mechanism; a so called mechanical interpretation of it doesn't do other than specifying the mechanism, and has a greater probability of moving it away from the truth, than of bringing it nearer [6].

3 Physics as an image of the world

Nevertheless, in spite of this standing, Ferraris held a well defined image of the world. It is not clear how the image of the world must be related with theories and facts, though some hints may be found in Ferraris' writings. If, for instance, we maintain that a particular vector field *exists*, then we may ask "where is the place of the elementary phenomena which give rise to the *existence* of the vector". Are the charges, considered as real entities of the external world, that produce the fields or are the fields the fundamental entities *existing* in the world? A look at the equations does not give the answer: in the equations we can consider the charges as the known quantities and the fields as the unknown ones; or vice versa. In the former case the charges 'produce' the fields; in the latter, the fields 'produce' the charges. According to Ferraris, the answer to this question, *'when possible'*, can be given only on the basis of other experimental facts, "for instance, facts showing an influence on the vector intensity by material media filling the field, or facts concerning the way by which the variations of the vectorial quantity propagate in space and time."

In the following, we can see how to build an image of the world concerning electromagnetic phenomena.

> Now, if the electric forces take some time to propagate, they stay some time in space with the corresponding energy. *The concept of a medium as the place of electromagnetic forces and energy is then inescapable*; and since the propagation speed of electric forces is equal to that of light, then the simplest and more legitimate hypothesis is that the body in which the electromagnetic energy lies and propagates is the same ether through which light propagates. *By now it is beyond any doubt*: the medium that transmits energy from the shaft of a hydraulic wheel to an electric engine far away, or from the fireplace of a steam engine to the carbon tips of a sparkling arc or to the carbon wires shining in bulbs, is the same through which and by which all available energy on this earth is coming from the sun.
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> [...]
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> And if, as foretold by Lamé, a day will come when also elastic forces will be explained by means of the ether [...] that day we shall have to say that everywhere and always, in the great machine of the universe and in those parts of it modified and fitted by us to the needs of our industries, the medium that transmits energy is only one, the ether [7].

And:

> Now, this is the consequence of this theorem [Poynting's]. In a wire in which an electric current flows, the electric force is longitudinal, while the magnetic one, perpendicular to the plane containing the axis, is tangential; the energy flux is then radial, directed inside. The energy does not flow longitudinally in the wire, but it enters from the outside, perpendicularly to the surface, and transforms into heat [...] The energy flows outside the wire; if the metal has null electrical resistance, the energy would flow entirely outside: the energy partially enters the metal and transforms into heat only when the electrical resistance is different from zero. The wire is not a channel in which the energy flows; it is a rail along which the energy flows outside: a part of the energy is dissipated inside as heat [...] Old habits, partially due to an old language, according to which the electric current is described as a liquid vein flowing in a tube, make these conclusions appear at first as unexpected, and even strange [8].

As already pointed out, Ferraris does not say which are the rules, if any, for building an image of the world. The electromagnetic case handled by Ferraris seems to indicate that the image of the world follows essentially and in an unique way from some particular experimental facts (see above his statements about the ether).

Furthermore, it is worth stressing Ferraris' strong ontological commitment about the existence of the ether and its role in energy transmission. This ether centered image of the world is particularly striking to us when applied to a current flowing in a wire: though Ferraris does not state it explicitly in this context, the argument can be applied also in the case of a steady current.

4 Ferraris and Hertz

Ferraris' philosophy of physics recalls, for many aspects, that of Heinrich Hertz. Hertz's philosophy is clearly outspoken in the introductions of two well - known books of him: 'The principles of mechanics presented in a new form' and 'Electric waves'.

4.1 The philosophy of physics of Heinrich Hertz

According to Hertz, the main goal of science consists in making predictions:

> The most direct, and in a sense the most important, problem which our conscious knowledge of nature should enable us to solve is the anticipation of future events, so that we may arrange our present affairs in accordance with such anticipation [9].

In order to get this goal,

> We form for ourselves images or symbols of external objects; and the form which we give them is such that the necessary consequents of the images in thought are always the images of the necessary consequents in nature of the things pictured [...] The images which we here speak of are our conceptions of things. With the things themselves they are in conformity in *one* important respect, namely, in satisfying the above - mentioned requirement [10].

These fundamental relations between ‘things’ and ‘images’ can be summarized in a table:

Table I - Relations between science and external world according to Hertz

External world		Science
Things	⇔	Images
⇓		⇓
Consequents of things	⇔	Consequents of images

However,

> The images which we may form of things are not determined without ambiguity by the requirement that the consequents of the images must be the images of the consequents [of things]. Various images of the same objects are possible, and these images may differ in various aspects [11].

We must choose among the various images according to the following criteria:

1. *the images must be logically permissible*, i.e. they must obey the laws of our thought
2. *the images must be correct*, i.e. they must obey our ‘fundamental requirement’
3. between two images ‘permissible and correct’, we must choose the more *appropriate*, i.e. the image that: a) is more *precise*, i.e. describes the greater number of essential relations of the object; and, b) is more *simple*, i.e. contains the smaller number of superfluous relations

These criteria can be grouped in the following table:

Table II - The criteria that, according to Hertz, must be used for evaluating our ‘images’ of ‘things’

Criterion	Control method	Control output	Type of control
Permissibility	Logical rules	Yes/No	Conclusive
Correctness	Experiment	Yes/No	Temporary
Appropriateness	Precision Simplicity	Questionable	Temporary

This framework can be applied also in a more technical context. Let us consider a physical theory expressed in axiomatic form. Then, table I must be replaced by the following one:[3]

Table III - The relations physics - external world, according to Hertz

External world		Physics
Things	⇔	System of equations
⇓		⇓
Consequents of things	⇔	Consequents of the system of equations

[3]Today, we would say that the ‘system of equations’ must be ‘interpreted’, i.e. that the physical quantities which appear in the equations can be, directly or indirectly, measured in a way specified by the theory and/or the acquired knowledge.

According to Hertz, the core of a physical theory is given by its system of equations. However, given a theory, i.e., given its system of equations, there can be many representations of the same theory. Representations of the same theory differ by their ontologies. Hertz does not use this term; instead, he speaks of different points of view. However, it is clear that different points of view are originated by different ontologies. Of course, according to Hertz, the choice among different representations of the same theory must be done on the basis of the appropriateness criterion.

The applications of these criteria by Hertz to the case of electromagnetism is illuminating. Hertz holds the view according to which the fundamental theoretical entities are the electric and magnetic fields, interpreted as 'states' of the ether. This point of view is, first of all, induced by a negative ontology: the rejection of the 'action at a distance', blamed as a kind of 'spiritual affinity' between two bodies; in the second place, by the choice concerning the existence of the ether. It follows that the 'electricity' is not only a secondary theoretical entity, but it is just a 'name' a 'notation' [12]: it is one of those elements that can be dropped without any loss in the predictive capacity of the theory.

However, Hertz's ontological commitment is cautious: in many instances the ether is referred to as 'hypothetical'. Consistently, Hertz's discussion of Poynting's theorem is very circumspect:

> In examining its physical meaning we must not forget that our analysis of the surface - integral was hypothetical, and that the result thereof is not always probable. If a magnet remains permanently at rest in the presence of an electrified body, then in accordance with this result the energy of the neighbourhood must find itself in a state of continuous motion, going on, of course, in closed paths. In the present state of our knowledge respecting energy there appears to me to be much doubt as to what significance can be attached to its localisation and the following of it from point to point. Considerations of this kind have not yet been successfully applied to the simplest case of transference of energy in ordinary mechanics; and hence it is still an open question whether, and to what extent, the conception of energy admits of being treated in this manner [13].

And, in a footnote added in 1891:

> Consider a steam - engine which drives a dynamo by means of a strap running to the dynamo and back, and which in turns works an arc lamp by means of a wire reaching to the lamp and back again. In ordinary language we say – and no exception need be taken to such a mode of expression – that the energy is transferred from the steam - engine by means of the strap to the dynamo, and from this again to the lamp by the wire. But is there any clear physical meaning in asserting that the energy travels from point to point along the stretched strap in a direction opposite to that in which the strap itself moves? And if not, can there be any more clear meaning in saying that the energy travels from point to point along the wires, or – as Poynting says – in the space between the wires? There are difficulties here which badly need clearing up [13].

These two long quotations show clearly how different were Ferraris' and Hertz's ontological commitments. The central issue concerning the ontological status of the energy and of its localisation is handled in opposite manners by the two authors: the ether based realistic view of Ferraris is contrasted with Hertz's refusal of any ontological choice.[4]

4.2 Side by side

The relations between images and things:[5]

Hertz

We form for ourselves images or symbols of external objects; and the form which we give them is such that the necessary consequents of the images in thought are always the images of the necessary consequents in nature of the things pictured [9].

Ferraris

The more abstract, the more probable is a theory. If a theory consists in equations corresponding to facts given directly by experience, it is all that we can today desire. The progress will consists in doing that equations will embrace tomorrow a greater number of experimental facts [5].

The core of a physical theory is its system of equations:

Hertz

To the question, "What is Maxwell's theory?" I know of no shorter or more definite answer than the following: Maxwell's theory is Maxwell's system of equations [17].

Ferraris

Maxwell's equations, or those of Hertz, summarize that part of our notions about the electromagnetic medium that, up to now, in the present state of science, is reducible to a precise form; they summarize what effectively is known from experience about the mechanical properties of the medium [6].

There can be many representations of the same theory (system of equations):

[4]Ferraris did know very well Hertz's position. He wrote: "[...] This means that the flux distribution indicated by Poynting is only one among the infinite other compatible with Maxwell's equations. Not always it may be the right one, among the infinite possible [distributions], as shown by some energy flows that will appear, according to it, in apparently stationary systems; from here stemmed Hertz's repugnance towards using this theorem. But, by now, we cannot doubt that the energy is transmitted by the ether; and to hold, with Hertz, that the principle of energy continuity, so clearly delineated by Poynting, does not find a prepared terrain in today science, is certainly an exaggeration [14]." And, in a note, Ferraris comments Hertz's note quoted above. By the way, it is worth noticing that the great majority of contemporaries textbooks of electromagnetism does not mention that the usual expressions of the electromagnetic energy density and Poynting vector constitute only a possible couple among infinite others. An exception is represented by *The Feynman Lectures on Physics* [15].

[5]In the case of Ferraris the role of 'images' and 'things' is played by 'theories' and 'experimental facts', respectively.

Hertz

The images which we may form of things are not determined without ambiguity by the requirement that the consequents of the images must be the images of the consequents [of things]. Various images of the same objects are possible, and these images may differ in various aspects [11].

Ferraris

Given the existence of the field, its distribution can be described in various ways. One of them consists in [...] an other way consists in[...] The two approaches are equivalent to two different choices of the quantities that are assumed as given or as unknown in a system of equations: the two approaches are equally legitimate and are equivalent; to choose one or the other does not mean to solve any physical issue [3].

The choice among several representations of the same theory should be made:

Hertz

Using the appropriateness criterion.

Ferraris

On the basis of particular experimental facts.

Theories and cloths:

Hertz

If we wish to lend more colour to our theory, there is nothing to prevent us from supplementing all this and aiding our powers of imagination by concrete representations of the various conceptions as to the nature of electric polarisation, the electric current, etc. But scientific accuracy requires of us that we should in no wise confuse the simple and homely figure, as it is presented to us by nature, with the gay garment which we use to clothe it. Of our own free will we can make no change whatever in the form of the one, but the cut and the colour of the other we can choose as we please [18].

Ferraris

[...] instead of materializing mathematical equations, by clothing them, so to speak, with false mechanisms, we must look at the geometrical tissue, which constitutes the skeleton of phenomena, in itself, as the most simple and genuine expression of them [19].

The ontology of electromagnetism, I:

Hertz

We now rather regard the polarisations as the only things which are really present; they are the cause of the movements of ponderable bodies, and of all phenomena which allow of our perceiving changes in these bodies. The explanation of the nature of the polarisations, of their relations and effects, we defer, or else seek to find out by mechanical hypothesis; but we decline to recognise in the electricities and distance - forces which have hitherto passed current a satisfactory explanation of these relations and effects. *The expressions electricity, magnetism, etc., have no further value for us beyond that of abbreviations* [20].

Ferraris

Now, if the electric forces take some time to propagate, they stay some time in space with the corresponding energy. *The concept of a medium as the place of electromagnetic forces and energy is then inescapable*; and since the propagation speed of electric forces is equal to that of light, then the simplest and more legitimate hypothesis is that the body in which the electromagnetic energy stays and propagates is the same ether through which light propagates [7].

The ontology of electromagnetism, II:

Hertz

In examining its physical meaning [Poynting's theorem] we must not forget that our analysis of the surface - integral was hypothetical, and that the result thereof is not always probable. If a magnet remains permanently at rest in the presence of an electrified body, then in accordance with this result the energy of the neighbourhood must find itself in a state of continuous motion, going on, of course, in closed paths. In the present state of our knowledge respecting energy there appears to me to be much doubt as to what significance can be attached to its localisation and the following of it from point to point. Considerations of this kind have not yet been successfully applied to the simplest case of transference of energy in ordinary mechanics; and hence it is still an open question whether, and to what extent, the conception of energy admits of being treated in this manner [13].

Ferraris

Now, this is the consequence of this theorem [Poynting's]. In a wire in which an electric current flows, the electric force is longitudinal, while the magnetic one, perpendicular to the plane containing the axis, is tangential; the energy flux is then radial, directed inside. The energy does not flow longitudinally in the wire, but it enters from the outside, perpendicularly to the surface, and transforms into heat [...] The energy flows outside the wire; if the metal has null electrical resistance, the energy would flow entirely outside: the energy partially enters the metal and transforms into heat only when the electrical resistance is different from zero. The wire is not a channel in which the energy flows; it is a rail along which the energy flows outside: a part of the energy is dissipated inside as heat [...] Old habits, partially due to an old language, according to which the electric current is described as a liquid vein flowing in a tube, make these conclusions appear at first as unexpected, and even strange [8].

The ontology of electromagnetism, III:

Hertz

Consider a steam - engine which drives a dynamo by means of a strap running to the dynamo and back, and which in turns works an arc lamp by means of a wire reaching to the lamp and back again. In ordinary language we say – and no exception need be taken to such a mode of expression – that the energy is transferred from the steam - engine by means of the strap to the dynamo, and from this again to the lamp by the wire. But is there any clear physical meaning in asserting that the energy travels from point to point along the stretched strap in a direction opposite to that in which the strap itself moves? And if not, can there be any more clear meaning in saying that the energy travels from point to point along the wires, or – as Poynting says – in the space between the wires? There are difficulties here which badly need clearing up [13].

Ferraris

By now it is beyond any doubt: the medium that transmits energy from the shaft of a hydraulic wheel to an electric engine far away, or from the fireplace of a steam engine to the carbon tips of a sparkling voltaic arc or to the carbon wires shining in the bulbs, is the same through which and by which all energy available on this earth is coming from the sun [7].

5 Conclusions

Ferraris' philosophy of physics appears as a rather well defined stand, though it reflects the lack of an organic effort. However, the nebulous area – the connection between the acquired knowledge and the image of the world – concerns an issue that has troubled many thinkers and troubles to a great extent also contemporary physicists and philosophers.[6]

Ferraris' position echoes that of Hertz. The main differences are: a) Hertz's viewpoint, unlike Ferraris', is the result of an organic reflection; b) Ferraris' overall ontological commitment is much stronger than Hertz's. This last point is of particular interest: Hertz's ontological options are cautious, particularly those concerning the ether, the energy, its localisation and transmission. Ferraris, instead, puts the ether and the energy in the focus of his image of the world: in some passages quoted above, the description of the role played by the ether in the energy transmission almost assumes the beats of a lyric.

[6] For a discussion of these topics, see, for instance, reference [21].

References

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[2] G. Ferraris, 'Teoria geometrica dei campi vettoriali', in: *Opere di Galileo Ferraris*, Volume I, Hoepli, Milano, 1902, 389 - 492.

[3] Ibidem, p. 451 - 2.

[4] Ibidem, p. 489 - 90.

[5] G. Ferraris, 'Sulla trasmissione elettrica dell'energia', in *Opere di Galileo Ferraris*, Volume II, Hoepli, Milano, 1903, p. 468.

[6] Ibidem, p. 467 - 8.

[7] Ibidem, p. 465 - 6; our italics.

[8] Ibidem, p. 461 - 2.

[9] H. Hertz, *The principles of mechanics presented in a new form*, Dover Publications, New York, 1956, p. 1.

[10] Ibidem; Hertz's italic.

[11] Ibidem, p. 2.

[12] H. Hertz, 'On the fundamental equations of electromagnetics for bodies at rest', in: H. Hertz, *Electric waves*, New York, 1962, p. 209.

[13] Ibidem, p. 220.

[14] Reference [5], p. 466.

[15] R. Feynman, R. Leighton, M. Sands, *The Feynman Lectures on Physics*, Volume II, Addison - Wesley, Redwood City, CA, 1963, p. **27** - 3 - 6.

[16] H. Hertz, *Electric waves*, Dover Publications, New York, 1962, p. 276 - 7.

[17] Ibidem, p. 21.

[18] Ibidem, p. 28.

[19] Reference [5], p. 468.

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[21] A. Casella, G. Giuliani, 'Il realismo come problema metodologico', in G. Giuliani Editor, *Ancora sul realismo - Aspetti di una controversia della fisica contemporanea*, La Goliardica Pavese, Pavia, 1995, p. 13 - 30.