# The contribution of history and philosophy to the conceptual approach of Physics. Old and new puzzles

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## Abstract

*Physics in textbooks is presented dogmatically, as if the physical magnitudes and laws are imposed by Nature. This sort of Physics refers to an idealized, not the real Nature. Moreover, the acceptance of a physical theory is determined from the preoccupations imposed by the culture of the time proper. Physics is the result of an endless effort to understand the World, so it cannot be dogmatic, as it is expected to change continuously. The current of different ideas, depicted in History and Philosophy, gives the opportunity to think about Nature making Physics a pleasant intellectual exercise.*

## Keywords

*Physics education, world image, theories and preoccupations, change of ideas*

## Résumé

*Dans les manuels scolaires, la Physique est présentée dogmatiquement, comme si les grandeurs physiques et les lois sont imposées par la Nature. Ce physique ne se réfère pas à la vraie Nature mais à une Nature idéalisée. Par ailleurs, l'acceptation d'une théorie physique est déterminée à partir des préoccupations imposées par la culture de son temps. La physique est le résultat d'un effort sans fin pour comprendre le monde, par conséquent, elle ne peut pas être dogmatique, car il est* *prévu de changer en continu. Le courant d'idées différentes représenté en Histoire et Philosophie, donne l'occasion de réfléchir à la nature physique faisant un exercice intellectuel agréable.*

**Mots-Clés**

*Enseignement de la Physique, image du monde, théories et préoccupations, changement d'idées*

## Introduction

In a textbook of Physics, usually the only thing one could find, are Physical laws expressed in words and in the form of mathematical relations between symbols corresponding to physical quantities, like l (length), t (time), F (force), etc. With this equipment the student is expected to become able to understand the World around us and to solve several exercises at the end of each chapter.

The restriction to this method includes three drawbacks:

1. Physics in the textbooks does not refer to the "real" Nature of senses, but to an idealized form of it the "World Image" (Planck, 1936)
2. Physics appear as dogmatic. The student cannot think of any different view, which seems erroneous beforehand and
3. Physical quantities seem as the only possible, imposed by Nature itself (Cornford, 1938a).

The purpose of this paper is to examine the three drawbacks mentioned above and find if Physics is really restricted to symbols, laws and ideas included usually in the textbooks of Physics.

## Real Nature – The Role of Measurements

In the World Image symbols correspond to physical quantities, which are considered absolutely exact, but in real Nature they must be replaced by their arithmetic values, resulting from measurements. However, measurements give values which are always burdened by an inevitable uncertainty, the experimental error (Taylor, 1982). Moreover, measurements can produce results, incompatible to other values of the same quantity, puzzling the scientists.

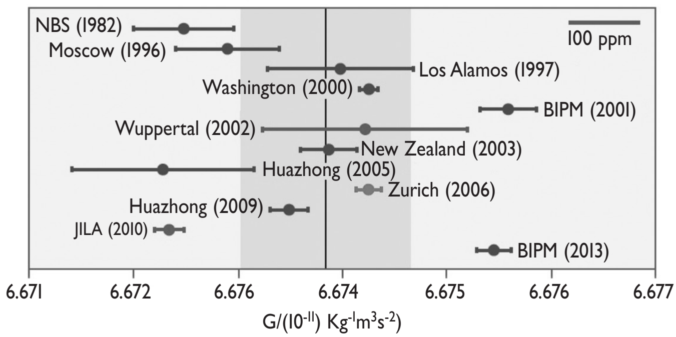
Let us see two examples:

Newton's law of Universal Gravitation is given by the well known relation

$$F = G\frac{m_1 m_2}{r^2}$$

where F is the force of attraction between the two point masses $m_1$ and $m_2$ and r the distance between them. In the world image G, the gravitational constant, is just a symbol of a physical quantity considered exact. If we want to use Newton's formula we have to measure G and replace this symbol with its value. In Fig. 1 the results of such measurements by different scientist are shown (Speace & Quinn, 2014).

**FIGURE 1**



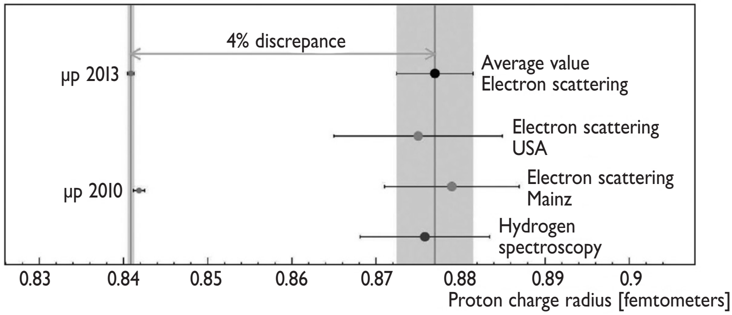

*In the idealized world-image Newton's constant R is considered unique and exact. However, when measured, different values arise varying much more than experimental errors can justify, puzzling scientists*

The uncertainty of each measurement is represented by a "horizontal" line, the error bar, which determines the range of values, in which there is a significant probability for the "exact" value of the constant G to be located. It is obvious that several values of G, represented by the black dots are mutually incompatible, because they are located outside the ranges determined by the errors. Indeed, for example NIST-82 and TR&D-96 lie well outside the range of the error bars of BIPM-01 and BIPM-13.

Is G in fact constant? There are theories which predict deviations from Newton's inverse square law at small length scales and other theories maintain that G depends on matter density at astronomical scales (Kapner, 2005). However, these theories are not widely accepted. Another possibility is that systematic errors much larger than their estimated uncertainties are involved in the measurements. "To find a precise value of G future experiments must be carrier out in laboratories having the highest quality of temperature and environmental control" (Speace & Quinn, 2014). Reality is more complicated than a theoretical image.

Another example is the determination of the proton's diameter. Proton is a fundamental constituent of matter, the fuel from which the Sun gathers energy. In Fig. 2 the results of previous, as well as more resent measurements are shown (Bernauer & Pohl, 2014).

**Figure 2**




*Recent measurements of proton's radius (on the left) give values incompatible with the results of older experiments (on the right). The effort to explain this may lead to significant alterations of physical laws*

The older results, on the right side of Fig. 2, are mutually compatible, as all the values lie in the range determined by the error bars. The acceptable value of the proton's radius is

$$(0.8775 \pm 51)\ x10^{-15}\ m$$

However, resent experiments gave the two values on the left side of Fig. 2, which although they have small errors, are completely incompatible with the previous values. According to these measurements proton's radius is

$$(0.8409 \pm 0.004)\ x10^{-15}\ m$$

Comparing the two values, we see that their difference is two orders of magnitude greater than the errors allow. According to the authors this unexpected difference "suggests that physicists do not understand something important about either the proton itself or the theory of quantum electrodynamics – until now the best tested and well understood theory of all of science. With any luck, the anomaly could lead to a fundamental revision of the laws of physics".

We see how important is the departure from the idealized World Image with its abstract symbols. Measurements, apart from their inevitable experimental errors, can reveal weaknesses of understanding the "real" Nature, leading to further investigations.

## Theories and Explanations in Physics. The Fundamental Role of Preoccupations

In Physics we find "theories", which can "explain" experimental results. These theories are the product of a creative imagination based on speculations, which may not been verified from direct observations, but from these theories result conclusions, which must explain experimental results. This gives the impression that the theory is "penetrating beneath the flux of phenomena to the real structure of nature" (Hesse, 1953).

Let us suppose that a theory can explain a wide range of phenomena; can we accept that it describes "real" nature? Not so! J.T. Cushing (1982) remarks about Quantum Field Theory (QFT) considered the most successful theory in high – energy physics: "When one looks at the succession of blatantly ad hoc moves made in QFT (negative – energy sea of electrons, discarding of infinite self energies and vacuum polarizations, local gauge invariance, forcing renormalization in gauge theories, spontaneous symmetry breaking, permanently confined quarks, color, just as examples) and of the picture which emerges of the "vacuum", as seething with particle – anti particle pairs of every description and as responsible for breaking symmetries initially present, one can ask whether or not nature is seriously supposed to be like that. A case can be made for scientists as clever people who make their theories work, rather than as discovering laws of nature which pre-exist outside their own minds…This is analogous to a suit which fits a person. There is certainly no unique suit which is the only one that fits. However, a bad fit is evident" (Cartwright, 1983).

It is obvious that the creation of a theory and its acceptance is determined by the preoccupations and the prevailing traditions of the social environment. Let's see the following examples:

When we lift a body from the ground, we feel its weight. How is it possible to explain this very common experience? Today one can say that the body is attracted by the Earth according to the Universal Law of attraction between masses proposed by Newton.

However, Plato in his dialogue "Timaeus", in which he exposes his Cosmology, gives a completely different explanation. His basic assumption comes from a widely accepted tradition, that similar have the "natural" inclination to be attracted by similar. So, when the body, which contains Earth (one of the four elements), is lifted from the ground, it is transferred into the region of a different element, the Air, so it tends "naturally" to get attached to the ground again, where the element Earth is concentrated.

Let's suppose now that we light a candle. Why the flame is directed upwards? Today one would say that the air above the candle is heated, expanded, acquires less density and so is lifted upwards by the surrounding air dragging along small carbon glowing particles. Plato would say that the flame is the element Fire, so it tends to be attached to the universal Fire surrounding Cosmos.

Let's suppose now that we throw a small object into the air. Today we can explain its movement as a simultaneous combination of a rectilinear motion along the initial velocity and a vertical fall under the influence of gravity. However, Aristotle could not think that a body was possible to move unless been pushed by something else in contact with it. Moreover, he could not accept that vacuum exists. So, he invented the following process; as the body moves, air from all-round rushes violently into the vacuum produced at the back of the body, pushing it ahead (in Greek: περίωσις, αντι-περίστασις) (Cornford, 1938b).

Obviously, if somebody were transferred to the times of Plato and Aristotle, he could not accept their approach to Nature. However, he would realize that neither his, nor the ancient philosophers' preoccupations are self-evident truths imposed by Nature. If they were, everybody should have all the time the same explanations everywhere on Earth.

## From the Continuous Laws of Classical Physics to the Discontinuity of Quantum Mechanics

It is not necessary to go back to antiquity to realize the difficulty to accept the "explanations" proposed by Physical Theories of different times. The transition from the continuous laws of Classical Physics to the discontinuous picture of the World of Quantum Mechanics was difficult, as it is shown from the following example:

At the end of September in 1926 Schrödinger visited Bohr in Copenhagen. The details of this visit are included in Heisenberg's book Der Teil und das Ganze (The Part and the Whole). Between the two men a passionate discussion continued for several days, during which Schrödinger expressed his doubts about electron jumps between discrete energy levels, an idea that Bohr supported with determination. The Schrödinger's objections are the following:

"You surely must understand Bohr that the whole idea of quantum jumps necessarily leads to nonsense. It is claimed that the electron in a stationary state of an atom first revolves periodically in some sort of an orbit without radiating. There's no explanation given why it should not radiate; according to Maxwell theory, it must radiate. Then the electron jumps from this orbit to another one and thereby radiates. Does the transition occur gradually or suddenly? If it occurs gradually, then the electron must gradually change its rotation frequency and its energy. It's not comprehensible how this can give sharp frequencies for spectral lines. If the transition occurs suddenly, in a jump so to speak, then indeed one can get from Einstein's formulation of light quanta the correct vibration frequency of the light, but then one must ask how the electron moves in a jump. Why doesn't it emit a continuous spectrum, as electromagnetic theory would require? And what laws determine its motion in the jump? Well, the whole idea of quantum jumps must simply be nonsense" (Moore, 1989).

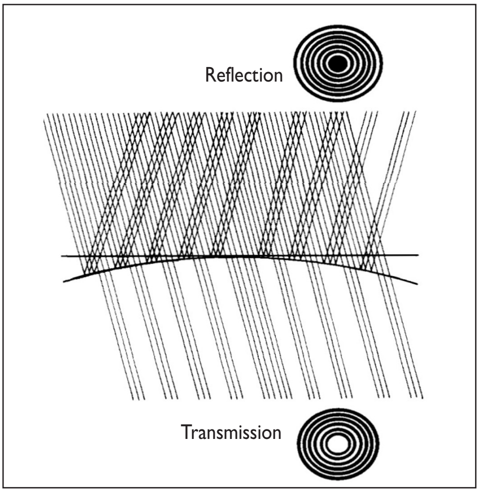
Schrödinger had a similar difficulty with the concept of particle. He thought that it is a small material body at a certain position, which according to Heisenberg's uncertainty principle is impossible not only to define, but not to think about it. The concept of orbit is lost by uncertainty, which takes the status of physical law (Bitbol, 1996).

## WAVES OR PARTICLES? DUALITY OF COEXISTENCE? FROM CONTINUOUS PICTURE TO PARTICLES AND VICE VERSA

Another difficulty arises from the fact that electromagnetic radiation and beams of atomic and subatomic particles exhibit sometimes wavelike behavior and some other times act like "material" corpuscles. A question arises from this. We have wave – particle duality, i.e. one and the same entity, which sometimes appears as a wave and some other times as a particle, or we have coexistence of a particle and a wave which directs it?

This question did not arise recently. Ironically Newton, who maintained that light was a stream of particles (atoms), discovered the rings which bear his name. When a plane glass sheet is placed on the convex surface of a plano – convex lens, an air film of gradually increasing thickness outward is formed between the sheet and the lens. If monochromatic light is allowed to fall on the sheet, alternate bright and dark concentric rings appear around the point of contact, as it is shown in Fig. 3.

**FIGURE 3**




*The periodicity of the rings shown, forced Newton to accept the coexistence and mutual interaction of light particles and a wave of unspecified nature (This picture is based on figure 4 of the Second Book of Newton's Optics)*

How was possible a stream of particles to acquire periodicity, a property exclusive to waves? To explain this Newton was obliged to accept that in parallel to the particles a wave propagates, which has a different velocity and acts on them. A part of the wave enforces the motion of the particle, though the other part impedes it. So, when the wave cooperates with the motion of the particle it can break through the surface of the convex lens (Fig. 3), but when the particle is in the other part of the wave which impedes its motion, it looses the ability to penetrate the surface and it is reflected (Sakkopoulos, 1988).

According to Maxwell's theory, the electromagnetic radiation has a continuous texture. However, in 1896 the experiments of J. J. Thomson and E. Rutherford in which X rays propagated through a gas indicated a discontinuous structure of the electromagnetic radiation. Only one in $10^{12}$ of the gas atoms was ionized. It was impossible to explain how a wave with continuous distribution of energy in space could ionize only an extremely small number of atoms in its way. The rejection of the continuous distribution of energy in electromagnetic radiation was a bold step, taken by Thomson who in 1903 during a lecture at Yale University in which described the wave front of a light wave as "an arrangement of bright specs on a dark background" (Wheaton, 1983). It is worthy of note that this daring opinion was a direct result of his older ideas. In 1893 Thomson had maintained that the field lines of an electric field may be imagined as very narrow tubes with real existence, not simply a mathematical tool of description. Taking into account that their number is limited, one results to a theory, which contains both particle and wave – like characteristics. A wave acquires a discontinuous structure in space as it is divided and propagated only along these field lines (Wheaton, 1983).

The transition of a continuous picture of energy to a discontinuous one was accomplished by the introduction of the concept of quanta by Planck in 1900. To find a theoretical explanation for the black body spectrum he proposed that energy is exchanged discontinuously in distinct packets, called quanta, each having energy $E = h.v$ where h is the Planck's constant and v the frequency of the radiation. At the beginning Planck did not realize the revolutionary consequences of this preposition, which later gave an interpretation for phenomena, which the Classical Theory could not explain, like the decrease of the atomic heats at temperatures approaching absolute zero. So, as time passed the idea prevailed that, not only matter, but energy as well had a discontinuous texture (Kuhn, 1978).

According to the Special Theory of Relativity energy exhibits inertia – mass and every mass is equivalent to energy. This gave the idea to Louis de Broglie that particles and photons are localized concentrations of energy. Consequently he tried to find the laws of motion of a particle connecting it with a periodic phenomenon analogous to the wave associate to the electromagnetic radiation. So, in 1923 Louis de Broglie came to a theory in which the particle is permanently connected to a pilot wave which directs its movement (Broglie, 1963).

Later, in 1926 Schrödinger based on this idea formulated the well known equation which bears his name. The subsequent elaboration led to the "orthodox" Wave Mechanics of the School of Copenhagen, in which the particle disappears and only the wave is kept (Broglie, 1973). In this theory the wavefunction Ψ appearing in Schrödinger's equation is a purely mathematic quantity without physical meaning. However, this wavefunction gives the most complete possible specification of a physical system, as the square of Ψ acquires physical meaning, giving the probability of the results of actual measurements on the system, which in this discussion is the particle (Cartwright, 2013). In the orthodox Wave Mechanics the double nature particle – wave is understood as dualism, not as coexistence of the type which Louis de Broglie accepted.

The viewpoint of Louis de Broglie led to another "heretic" interpretation of Wave Mechanics by David Bohm, in which Ψ acquires physical meaning. It describes a real pilot wave which exerts a force on the particle directing it to regions, where the square of Ψ takes high values (Bohm, 1952).

It is remarkable that Bohm described Ψ as a field, a kind of fluid, in which the particle moves. Moreover, he considered that the field and the particle are not different identities, but in the fluid small systematic fluctuations (concentrations of the field energy) take place, which appear as localized particles. Each of these energy concentrations appears, dissolves and reappears again with great probability in a short distance giving the impression that a small particle follows a certain path (Karimäki, 2012).

Moreover, Bohm expressed the opinion that particles, which are considered elementary, i.e. are not composed of smaller particles, in the future may be found that they are composite. Indeed, at the beginning atoms were thought simple corpuscles, but later it was found that they are composed of electrons, protons and neutrons. Eventually, the latter two were found to consist of more elementary particles, the quarks. Only the electron remains elementary. But things do not stop here. In the article "The inner life of quarks" Don Lincoln (2012) remarks that the repeating patterns observed for the 12 elementary particles may suggests that these are consisted of smaller particles (called preons). This is analogous to the repeating pattern of chemical elements noticed by Dimitri Mendeleev in 1869, which physicists later explained as a consequence of atomic structure.

In the above discussion the expression "particle" was used. But finally what is a particle? How is it possible to image it? The answer is not easy! In the David Tong's article (2012) he reports that quantum theorists often speak of a world which is made of district pieces at the smallest scales, like a mosaic. This is not correct. "The building blocks of physical theories are not particles but fields: continuous, fluidlike objects spread throughout space…The objects we call fundamental particles are not fundamental. Instead they are ripples of continuous fields". These ideas are analogous to Bohm's suggestions, who had the opinion that the fundamental entities in Nature are the continuous fields.

Although it seems, mostly from impressive technological applications, that Physics has managed to explain a great part of Nature, important challenges remain. In 1932 the Dutch Jan Oort and in 1933 the Swiss astrophysics Fritz Zwicky studying the movement of a distant cluster of galaxies came to the conclusion that it should be a much greater amount of mass exerting gravitational force than the one which observed. This mysterious invisible matter, which does not absorb or emit electromagnetic radiation (light, X – rays, etc.) but acts on the visible matter with gravitational force, is called "dark matter" and it is not known from what sort of particles is made.

In 1998 and 1999 astronomical observations from two different scientific groups showed that the Universe is expanding with accelerating velocity, although it must contract, as the gravitational forces direct towards its center. For the description of this terrifying fact, because it will finally cause the dissolution of the Universe, the concept of a new type of energy of unknown origin was introduced, the dark energy. This extends to all space and generates a repulsive force between masses, opposite to that of Gravity. It is estimated that the observable Universe consists of 26.8% dark matter, 68.3% dark energy and only 4.9% usual matter.

## Conclusions

Modern Physics, as every aspect of Nature in every age and culture, is the outcome of a continuous effort to understand Cosmos, which surrounds us. Consequence of this struggle is the endless change of Physics. Whatever is considered unquestionable today, tomorrow may be regarded a theory of the past. This is confirmed by the History, which comes to protect us from the arrogance of omniscience.

This is not the only one. History together with Philosophy comes to dismiss the boredom of the dogmatic laws and symbols of the Physics textbooks, to depart students from a superficial view of Nature and give the character of mental exercise to the study of Physics. Nature is one, but the ways of comprehending and describing its function are many. For a given phenomenon several explanations can be proposed and here is the importance of the role of History and Philosophy, to make the mind to speculate, to accept or to reject an explanation of a natural phenomenon. Deprived from History and Philosophy, Physics loses the most interesting and admirable part included in the struggle of human mind to understand and explain the surrounding World.

Let us finish with a characteristic extract from the poem "On Nature" composed by Empedocles from Acragas (c. 492 – 432 B.C.), which shows off dramatically the limits of human knowledge.

"Narrow are the powers that are spread through the body, and many the miseries that burst in, blunting thought. Men behold in their span but a little part of life, then swift to die are carried off and fly away like smoke, persuaded of one thing only, that which each has chanced on as they are driven every way; yet each boasts that he has found the whole. So little are these things to be seen or heard by men, or grasped by the understanding" (Guthrie, 1980).

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