AN ANALYSIS OF THE CERTAIN ELEMENTS OF THE PHILOSOPHICAL AND MATHEMATICAL FOUNDATION OF PHYSICS

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Abstract

Even non-physicists know that a great deal of mathematics is used in the physical sciences, engineering, economics, etc. Now, it is entering areas like life sciences. However,it is also vaguely known and we only try to bring it in sharper focus here that the mathematics applied in these areas is so much more permissive that a purist might go to the extent of saying that much of it has no more than formal resemblance to mathematics. For these reasons, the attitude towards their disciplines, of the mathematician on the one hand, and the theoretical physicist or even the mathematical physicist/applied mathematician on the other, are very different. For instance, the former does not regard infinity as a number; the latter treat it almost like any other number. Whereas the mathematician regards infinity as a signal of breakdown, it is not always so to the theoretical physicists for whom it is sometimes quite innocuous, sometimes useful or convenient, and sometimes it even rescues him from some rather awkward predicament, as, for instance, the singularity in second-order differential equation in quantum mechanics (as also in many cases in classical physics) allows only one of the two solutions to be acceptable, thereby givinghim a unique solution. (We may call this situation as 'infinity rescuing physics'). Of course, there are also many other situations where occurrence of infinity, or other niathematical improprieties, makes the theoretical physicist very unhappy. Very similar are the contrasting attitudes of the pure mathematician on the one hand, and applied mathematicians of all hues (including theoretical physicists) on the other, with regard to other mathematical improprieties. All these things do not have the approval of mathematical orthodoxy, as symbolized by institutions such as those of the Bourbakis.

Paper Identification

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Introduction

One of the consequences of this shortcoming is that either there is a mad rush, without much thinking, for everything scientific in the spirit of scientism', or there is obscurantism as the reaction to this unthinking scientism, in which, as stated by the positivists, the age of mythologies refuses to budge and pass into the higher realms of metaphysics and positive science, with all its attendant consequences for the polity and ethos of the country and its people. This humble thesis can be seen as a modest attempt to set the ball rolling in the direction of further fruitful studies in the history and philosophy of science in India so that the universities can play a better role in shaping up the thinking of the people for a better world for today and tomorrow. In recent times, philosophies of science have been sought to be grouped under the headings of logical empiricism, critical rationalism, neo-realism and dialectic materialism [Naletov 1984]. In our chapter 'On the Methodology of Physics' and the Appendix entitled 'Phenomenologism as Anti-Realism*, we have looked at phenomenalism and realism as they refer to the methodology followed in physics. Phenomenologism has been sought to be justified as a more truthful exposition of physics by Nancy Cartwright but her attitude, as claimed by herself, is one of anti-realism [Cartvright 1983]. Husserl's phenomenalism endorses Hume and finally reduces to anti-realism as explained by [Hasan 1928], but Cartwright is critical of Hume and clarifies that her stance is different from the extreme anti-realism of" the constructive empiricist van Fraassen and the positivist Duhem. Our study of phenomenology of hypernuclear and other physics should perhaps be seen as case studies in physical realism rather than anti-realism, although we feel a debate at a more exhaustive level is not inappropriate even at this stage.

On the Methodology of physics

Origins of the modern scientific method

The essence of modern scientific method is theorization based on abstract concepts which are often expressible mathematically, and experimentation. Modern science progresses by the interplay of theorization and experimentation. Experiments may be specially designed to test some hypothesis which may be confirmed or modified depending on the results of observations. In this way theories may emerge and subsequently may be expanded, modified or replaced. Constant verification ensures that the theory does not lose sight of observed facts and thereby a realistic insight into the working of the world is hoped to be achieved. We will not go here into the various philosophies that claim to describe the scientific method the best. We will look here at the historical emergence of the new method, and later will give some examples of actual investigation in physics that would illustrate it in practice.

It is often implied that Galileo Galilei (1564-1642) was the first major proponent of the new scientific method. For example, Galileo disproved Aristotle when he showed that, if dropped freely from a height, both a heavy and a light stone take identical time to fall to the ground, unlike the expectation on Aristotelian view that the heavier body must fall faster. Galileo proceeded by the method of experiments and also succeeded in formulating a mathematical description of the motion of the bodies, although it took a Newton to finally get the equations of motion that go by his name. The Scientific Revolution in Europe, during the 16th and 17th centuries, has been supposed to be triggered by Galileo's new approach. Moreover, this was supposed to be a revolutionary break from the ideas of the scholastics of the centuries preceding Galileo. This, it turns out, however, is not quite the full truth.

Before Galileo, Copernicus (1473-1543) had already disproved that the earth was the center of the universe as was believed on the authority of ancient texts and philosophies such as that of Aristotle. Then Rene Descartes (1596-1650) in his book Discourse de la Methode (Discourse on Method) criticized those who 'have faith merely in ancient books' i.e. those who do not test authority with experience and experiment. The Cartesian view ultimately lead to a mechanistic philosophy of science from which, according to some, the post-quantum mechanical world is today trying to liberate itself. However, the roots of the scientific method, as we have already indicated, were laid by people like Ibn al Haytham, who describes his research methodology in the following words, in one of the tracts that he wrote entitled 'Doubts about Ptolemy ':

'Truth is sought for its own sake. It is not the person who studies the books of his predecessors and gives a free rein to his natural disposition in regarding them favourably who is the (real) seeker after truth. But rather the person, who in thinking about them, is filled with doubts...who follows proofs and demonstrations, rather than the assertions of a man. . . a person who studies scientific books vith a viei/ to knot/ing the truth, ought to turn himself into a hostile critic of everything that he studies. . . If he takes this course, the truth will be revealed to him and the flaws. . . in the writings of his predecessors will stand out clearly. ' 'All natural phenomena are the consequences of their (fundamental) principles. Actually these principles are subtle and hidden to the highest degree. . .They are not accessible to the sense perception."Finding the truth is difficult and the road to it is rough. For the truths are plunged in obscurity. '

Methodology in modern physics

General features

The basis of all science including physics is systematic observation. This holds for modern quantum physics just as it did for classical physics. On the theoretical side, at the same time, both in classical as well as quantum physics there is ever increasing application of mathematical methods. Thus the steps inscientific methodology in all physics are: observations leading to enunciation of laws which in turn also lead to principles, and attempts to theorize on the basis of observed phenomenon, often involving first hypothesisadvancing and then model-making. Models are ultimately expected to lead to theory. These days so many people are working that the hypothesis stage is very short, sometimes being intangible. A hypothesis is either rejected in the light of new facts or goes to become a model in no time. However, the stage of the theory has not been reached to the same extent in all the disciplines of physics. Mechanics, Special and General Relativity and Maxwell's Theory have a high prestige in classical physics. On the quantum side, nothing matches Q.E.D. in prestige because of the fantastic degree of its success, although the mathematical status seems shaky. Even non-relativistic quantum mechanics has many achievements. However, when it comes to the study of systems like molecules and specially nuclei, one hardly has anything that can be classed as proper theory except for very limited purposes, although the term nuclear theory is frequently used. This is largely a misnomer. The difficulties are mainly those of a many body problem which is compounded in the nuclear case by the nature of the force.

1) Old Ideas Keep Coming Back;

Old discarded ideas often keep coming back, generally with a modified meaning. We give just three examples:

a) The photon is an heir to Newto' corpuscle. Of course, the former is not the same as latter.

b) First air, water, earth and fire were the elements out of which everything else was supposed to be formed. This is no longer believed to be the case, but the idea of element has survived. Now there are about ninety stable or fairly stable elements.

c) Although atoms as conceived by Democritus, Lucretius or Epicurus in the ancient world, or by medieval philosophers, are very different from the modern conceptualizations of atom, according to Feynman in his famous Lectures on Physics, the idea that everything is made up of atoms is the single most important statement that can be made to characterize the physics of today.

These examples serve to remind us that we may keep nodding acquaintance with the landmark concepts in the history of science.

2) People do not have Monopoly over Ideas:

Generally, a single person is not the sole author of any major concept. We give some examples:

a) Apart from Rutherford, idea of the nucleus had also been given by a Japanese physicist.

b) The important idea of synchrotoron action had been given by McMillan in U.S.A. and Veksler in Europe almost simultaneously.

c) The idea that the nuclear atom consists of neutrons and protons was given independently by Heisenberg in Germany and Ivanenko in Rv xa and although Majorana had arrived at the same conclusion at about the same time he never got round to publishing it.

d) Recently, it has been found out that Euler had given essentially the same theory as Huygens about light as waves, except that he had developed his theory for pulses instead of continuous waves.

The Principle of Elimination of Infinities:

It is not just in classical mathematical physics that appearance of infinity or other improprieties is sometimes regarded as a failure of the mathematical structure, caused in its turn by a defective physical model, so that the infinity or mathematical impropriety is taken as an indication of the neglect of some physical reality, as e.g. damping in mechanical systems, or viscosity in boundary layers in fluid flow, etc.. When the realistic component is introduced into the mathematical model, the infinity or impropriety is removed. The philosophy is that infinity, in the spirit of Hilbert, has no place in the actual physical world, and so if it arises in some mathematical calculations, based on a certain modeling of a physical situation it would imply that the model is unacceptable, as it must be unphysic2l|L i some respect at least infinitesimally," indicating the \^

It is by no means obvious that this principle of the elimination of infinities should necessarily be taken over into Quantum Physics. If it is literally taken as a guiding principle in Quantum Physics also, the appearance of improprieties might be taken as an indication of the need for some new physical input even in Quantum Mechanics, in situations where improprieties arise there. However, this principle has far reaching implications to be proposed casually. It needs a thorough debate and a lot of work before anything can be said about the matter. Calling it the Principle of Elimination of Infinities and other Mathematical Improprieties in conventional physics, we finally note that this principle, thus, stands to be carefully examined in the light of what we have discussed above and in the light of Thorn's theory of catastrophes which has been shown to have important implications for as diverse fields as theoretical biology, geology, atmospheric physics, linguistics and social biology [Thorn 1975]. In fact, as we have pointed out, singularities have always been required to describe sources and sinks, etc., so that the programme of adding newer and fresher physical interpretations, to the mathematical syntax in use in physical theories, represents an area of on-going physics research, in which new and interesting surprises can be expected to be in store for the physicist.

To Have or Not to Have

the fact that one of the solutions is always irregular at a singular point provides a unique prescription in quantum mechanics. This indicates that singularities are not always bad. They could be useful also. Segal [1991] adduces interesting examples to argue that occurrence of infinities, instead of being an embarrassment. can turn out to be benign. Even so, the word has a relative significance. For example, in geometrical optics of lenses, a distance of greater than a few times the focal length may be as good as infinite. Similarly, infinite ohmic resistance signifies that no current flows. As a matter of fact, R = O (superconductivity) presents a problem in the ordinary electrodynamics, and leads to the modified phenomenology given, for example, by London [London 1950], Thus, here, in these examples, infinity has nothing' diabolical about it. Depending on the nature of problem being solved, a quantity may be taken as infinite in one framework but may be quite finite in the other

Non-Conventional Logic-.

In rather recent times, even in mathematical logic, strict adherence to class'ical two-valued logic with its Aristotelian principle of the excluded middle (either a e A or a / A implies that there is no third possibility) has been given up, and one talks today of fuzzy sets [Fraenkel 1958]. Incidentally, these sets are being employed in some modern electronic devices. In mathematical intuitionism, as interpreted by Brouwer, the indiscriminate use of the law of the excluded middle, for example, is sharply criticized [lyanaga and Kavada 1980]. ^Either there exists a natural number with a given property P or else no such number exists' is to be regarded as proved or disproved only when an actual construction is given. When neither of these two results can be shown, then one can not say anything about the truth of the above proposition. Moreover, in the theory of trans-finite numbers, Godel's proof of the logical impossibility of simultaneous completeness and consistency of axioms has been well known [Ershov and Palyutin 1984]. We might speculate that departure from rigidly definite positions and assertions in pure mathematics might well have been inspired by developments in quantum physics.

Critical Discussion of Dirac's Cartesian Principle:

It has already been mentioned. So we do not state it again here. We examined it for quantum mechanics as well as saw if there was any preference of the Cartesian Coordinate system in classical physics. We found it to be a false premise. The Dirac Calrtesian principle, as stated herein, implies that the irregular solution should be excluded completely at all points except at infinity. Our investigation shows that the irregular solution is not a solution of the equation in question at the origin, but is a regular solution at all the other points. In the quantum mechanical treatment of the scattering problem where the origin is excluded, the solution, irregular at the origin, is mixed with the regular solution, from which fact the phase-shift is obtained. Thus, for the square-well potential, which is an extreme situation, the origin is excluded for all the region outside the well. Here the irregular solution is mixed with the regular one. The mixing produces the phase shift. If there were no mixing of the irregular solution, phase shift would be zero, but in physical situation, scattering occurs when a particle beam is shot on a target. One may say that since the square well is unrealistic, the discussion may not prove anything. However, even with smoothly varying potentials, the mixing takes place progressively. The mixing of the irregular solution here too gives rise to phase shift and hence to scattering, so occurrence of scattering in so many microscopic situations in nature may be taken as proof of the mixing of the solution, which is irregular at the origin for all kinds of potentials. This argument shows quite clearly that Dirac's Cartesian Principle does not hold. However, the Cartesian system has a preferential role in quantizing a classical system.

The Principle of Elimination of Infinities:

It is not just in classical mathematical physics that appearance of infinity or other improprieties is sometimes regarded as a failure of the mathematical structure, caused in its turn by a defective physical model, so that the infinity or mathematical impropriety is taken as an indication of the neglect of some physical reality, as e.g. damping in mechanical systems, or viscosity in boundary layers in fluid flow, etc.. When the realistic component is introduced into the mathematical model, the infinity or impropriety is removed. The philosophy is that infinity, in the spirit of Hilbert, has no place in the actual physical world, and so if it arises in some mathematical calculations, based on a certain modeling of a physical situation it would imply that the model is unacceptable, So appearance of any mathematical impropriety is considered to be a signal for the improvement of the model to be carried out, based on sound physical principles. However, it must be remembered here, as already point out, that infinities and singularities may be potent in meaning, as for instance qualitative arguments of Thorn's theory of catastrophes suggest that singular points may be nuclei of catastrophic change, starting from a local perturbation to a global scale like a phase change or occurrence of spontaneous magnetization, etc. [Haken 1983].

On the quantum theory

Failures of classical physics

In recent times. Quantum Theory had its origin in the inability of Classical Physics to account for the experimentally observed energy distribution in the continuous spectrum of black-body radiation. Planck started with the simplest possible assumption that the radiators are linear harmonic oscillators of frequency v. Using Boltzman's probabilistic conception of entropy, Planck found it necessary to treat energy as consisting of discrete energy elements hv, where h was a constant independent of h. As it turns out, h is a fundamental constant of physics. Meanwhile, Einstein stated that radiation consisted of discrete photonsan idea that was completely at variance with the prevailing undulatory electromengnetic theory of light. Einstein also constructed a quantum kinetic theory on the basis of his ideas and was able partly to explain the nature of specific heat of solids at low temperatures. Meanwhile, a hypothesis was suggested by Sommerfeld that atoms gain or lose definite h amounts fraction' given by W = h/2n

Nineteenth-century models of atoms, such as those proposed by Kelvin, Helmholtz or Bjerknes were primarily mechanical or hydrodynamical, and were invalidated by the discovery of electrons and radioactive disintegration. Thomson's model, namely that of a positively charged sphere of radius -lo'^cm, with an electron oscillating at the center, failed to account for the large angle deflections, of upto 150 , with reference to the incident direction, in the scattering experiments with a-paricles carried out by Geiger and Marsden. The Rutherford model of the atom, with a small positively charged nucleus surrounded by orbiting electrons could explain large-angle a-scattering, but, as Bohr realized, could not be reconciled with Newtonian mechanics and Maxwell's electrodynamics ^t the same time. It had occured to Rydberg, and was later explicitly stated by Ritz as a fundamental principle, that the frequency of every spectral line of an element could be expressed as the difference between two terms, each of which contained an integer. For example, Balmer's formula and its generalizations could be expressed by the equation.

Bohr summarized all his assumptions in the following formulation :

(1) that energy radiation is not emitted (or absorbed) in the continuous vay assumed in ordinary electrodynamics, but only during the passing of the systems betureen different 'stationary' states,

(2) that the dynamical eguilibrium of the systems in the stationary states is governed by the ordinary lavs of mechanics, vhile these lavs do not hold for the passing of the systems between the different 'stationary' states

(3) that the radiation emitted during the transition of a system between two stationary states is homogeneous, and that the relation between the frequency v and the total amount of energy emitted, namely E, is given by E=hv, where h is Planck's constant,

(4) that the different stationary states of a simple system consisting of an electron rotating round a positive nucleus are determined by the condition that the ratio betveen the total energy emitted during the formation of the configuration, and the frequency of revolution of the electron, is an entire multiple of h/2. Assuming that the orbit of the electron is circular, this assumption is equivalent to the assumption that the angular momentum of the electron round the nucleus is equal to an entire multiple of h/2Tl.

(5) that the 'permanent' state of any atomic system i.e. the state in vhich the energy emitted is a maximum, is determined by the condition that the angular momentum of every electron round the centre of its orbit is equal to h/2Tl [Jammer 1966].

Conclusion

The logic of physics is syntacto - semantics in the sense that mathematics provides the logical syntax (syntactics) to which is added a specific physical interpretation (semantics, or meaning) to provide a complete physical theory. The same material structure may, therefore, be described by several mathematical structures, each with its own corresponding physical interpretation [Strauss 1972]. For example, observables in Quantum Mechanics can be thought of as matrices in Heisenberg's Matrix Mechanics or as functions in Feynman's Path-Integral approach, or as elements of an Abstract Algebra a la Dirac, or as Self-Adjoint Operators in the Hilbert space a la von Neumann, etc.. Of these many supposedly equivalent formulations, one or the other may be best suited to a specific problem [Omnes 1992]. se, dependent on the case being considered. In many physical situations, explicit time-dependence may be factored out in a suitable way and the time-independent modes supposedly give stable, or stationary, solutions in time. Transitions between these equilibrium or stable states can then often be studied by adding time-dependent perturbation terms to the equations. Otherwise, the factor exp (-iwt) simply means that the ^stable' solution just keeps on propagating onwards in time. If the solution can be represented as a vector in some imaginary Platonic world, exp (±iwt) simply means that the vector keeps on steadily rotating as time goes on, traversing an angle wt in time t, either in a counter-clockwise or clockwise direction.

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