APPRAISAL OF NEWTON'S MECHANICS AND OF EINSTEIN'S "*AUTOBIOGRAPHY*"

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IN 1949, Albert Einstein wrote for a Volume, devoted to his world outlook (Albert Einstein, Philosopher-Scientist, Illinois, USA, 1949), an article which contains a brief definition of the state of physics at the time he embarked on his creative work. On this occasion he appraised the principles of classical physics, those of Newton's mechanics.

At the turn of the century, the conception was still valid of Newton's laws of motion as being the final solution of the fundamental problems of being. "In the beginning (if there was such a thing), God created Newton's laws of motion together with the necessary masses and forces. This is all; everything beyond this follows from the development of appropriate mathematical methods by means of deduction" (p. 19).

According to Einstein, the XIX century provided sufficient grounds for such opinion of the Newton's laws of motion. Particularly striking were the successes achieved by the theories which applied the equations in partial derivatives. Newton's theory of the propagation of sound was the first classical example of applying such differential equations. Later Euler gave the differential equations of hydrodynamics. This belongs to the theory of propagation of deformations in a continual medium. According to Einstein, the XIX century was noted for a systematic and detailed study of the motion of discrete bodies, the mechanics of the latter forming the basis of physics as a whole.

When Einstein became acquainted with the principles of classical physics, he was most impressed not so much by the structure of Newton's mechanics and the methods of solving mechanical problems, as by the application of mechanics to proper physical and physico-chemical problems. Einstein enumerates the results of applying mechanical conceptions in physics: optics as the mechanics of quasi-elastic ether, the kinetic theory of gases and atomistic chemistry (which, however, stood quite apart in the mechanical natural science of the XIX century).

Einstein wrote about himself and his student years comrades: "What made the greatest impression upon the student, however, was less the technical construction of mechanics or the solution of complicated problems than the achievements of mechanics in areas which apparently had nothing to do with mechanics: the mechanical theory of light, which conceived of light as the wavemotion of a quasi-rigid elastic ether, and above all the kinetic theory of gases: the independence of the specific heat of monatomic gases of the atomic weight, the derivation of the equation of state of a gas and its relation to the specific heat, the kinetic theory of the dissociation of gases, and above all the quantitative connection of viscosity, heat-conduction and diffusion of gases, which also furnished the absolute magnitude of the atom. These results supported at the same time mechanics as the foundation of physics and of the atomic hypothesis, which latter was already firmly anchored in chemistry. However, in chemistry only the ratios of the atomic masses played any rôle, not their absolute magnitudes, so that atomic theory could be viewed more as a visualizing symbol than as knowledge concerning the factual construction of matter" (p. 19).

Classical mechanics may serve as the basis of thermodynamics. True enough, this requires a statistical assembly of molecules whose motions are subordinated to the relationships of thermodynamics which are backed by the immutable laws of motion and collision of bodies established by Newton's mechanics. That is why classical thermodynamics was regarded, and indeed was, a testimony of the universal nature of Newton's mechanics. Einstein wrote that ". . . . it was also of profound interest that the statistical theory of classical mechanics was able to deduce the basic laws of thermodynamics, something which was in essence already accomplished by Boltzmann" (pp. 18-20).

Newton's classical mechanics was considered to be the basis of electrodynamics as well. This quite naturally resulted from the universal interpretation of classical mechanics. Maxwell's and Hertz's deliberate tendency was to substantiate electrodynamics from a mechanical standpoint. At the same time the objective historical tendency, which forced its way in classical electrodynamics, consisted in refusing to accept classical mechanics as the basis of physical ideas.

Einstein wrote: "We must not be surprised, therefore, that, so to speak, all physicists of the last century saw in classical mechanics a firm and final foundation for all physics, yes, indeed, for all natural science, and that they never grew tired in their attempts to base Maxwell's theory of electromagnetism, which, in the meantime, was slowly beginning to win out, upon mechanics as well. Even Maxwell and H. Hertz, who in retrospect appear as those who demolished the faith in mechanics as the final basis of all physical thinking, in their conscious thinking adhered throughout to mechanics as the secured basis of physics" (p. 21).

Einstein perceived a deliberate revision of classical mechanics in Mach's work, *History of Mechanics*. Here one has to differentiate strictly: (1) The idea that it is impossible to erect the building of science on the foundation of classical mechanics: (2) The so-called Mach principle according to which inertia forces are a function of the interaction of masses; (3) Mach's philosophical views.

As to refusal to accept a dogmatic and universal comprehension of classical mechanics, Einstein read in the *History of Mechanics* more than it contained; Mach disputed the idea of absolutely accelerated motion in the way it was expounded in Newton's "Principles". The famous example of the revolving bucket appeared unconvincing to Mach. But his remarks did not imply, even in a vague form, the notion of other, non-classical regularities of mechanics and did not lead to the assumption of non-mechanical initial regularities of nature.

As to the philosophical ideas of machism, Einstein felt their influence in his youth, but later he consistently departed from Mach's positions to an ever-increasing extent until he passed his well-known remark about Mach as the "déplorable philosopher".*

In his criticism of Newton's mechanics, Einstein proceeded from criteria fundamentally different from those of Mach. For Einstein, the first criterion of any physical theory consisted in its conformity with the results of an experiment, by which Einstein meant cognition of the objective processes in nature. *Physical theory should conform to experiment.* But this is far from warranting directly the correctness of the theory; the results of an experiment may conform to various conceptions, and a current conception can very often be brought to accord with an experiment by means of additional hypotheses. As a matter of fact, a conception which explains a number of experimental results in a non-contradictory way does not yet possess warranted oneness, since it can be replaced by another, sometimes more general, conception which accounts for a wider range of facts.

The case in point is, however, not the extension, precise definition and generalization of the theory in connection with transition to another, wider range of phenomena. "Of the 'realm' of theories I need not speak here, inasmuch as we are confining ourselves to such theories whose object is the totality of all physical appearances" (p. 23).

Hence Einsteins's first criterion admits of but one alternative appraisal: the theory in question either accords or does not accord with the *totality* of known physical phenomena. Naturally enough, such a conformity cannot be guaranteed for the future as the volume of empirical physical knowledge constantly increases. It is precisely for this reason that the criterion of conformity with facts (Einstein called it the criterion of "external justification") is always valid in assessing a scientific theory.

The second criterion was termed by Einstein the criterion of "inner perfection". This implies the following:

Every theory can be defined, sometimes by intuition, and sometimes in a comparatively strict way, by the degree of its logical harmony. Einstein formulated this criterion very cautiously, pointing to its inaccuracy.

"The second point of view is not concerned with the relation to the material of observation but with the premises of the theory itself, with what may briefly but vaguely be characterized as the 'naturalness' or 'logical simplicity' of the premises (of the basic concepts and of the relations between these which are taken as a base). This point of view, an exact formulation of which meets with great difficulties, has played an important rôle in the selection and evaluation of theories since time immemorial" (p. 23).

This criterion should not be reduced to determining the number of independent assumptions from which the theory proceeds. Einstein wrote about the non-comparability of the logical "quality" of one theory with that of another competing theory. Apart from a number of independent premises, their "strength" is of importance, *i.e.*, the possibility of determining unambiguously the resulting assertions, with the exclusion of others.

"The problem here is not simply one of a kind of enumeration of the logically independent premises (if anything like this were at all unequivocally possible), but that of a kind of reciprocal weighing of incommensurable qualities. Furthermore, among theories of equally 'simple' foundation that one is to be taken as superior which most sharply delimits the

* E. Meyerson, *La déduction relativiste*, Paris, 1925, p. 62.

qualities of systems in the abstract, *i.e.*, contains the most definite claims" (p. 23).

Yet another component, "inner perfection," is added to the "naturalness" (logical simplicity) of the theory. The theory is more perfect if it has been selected with maximum compulsion and with least arbitrariness.

"The following I reckon as also belonging to the 'inner perfection' of a theory: We prize a theory more highly if, from the logical standpoint, it is not the result of an arbitrary choice among theories which, among themselves, are of equal value and analogously constructed" (p. 23).

Einstein did not claim that he formulated his criteria in a precise manner: "The meagre precision of the assertions contained in the last two paragraphs I shall not attempt to excise by lack of sufficient printing space at my disposal, but confess herewith that I am not, without more ado (immediately), and perhaps not at all, capable to replace these hints by more precise definitions. I believe, however, that a sharper formulation would be possible. In any case it turns out, that among the "augurs" there usually is agreement in judging the 'inner perfection' of the theories and even more so concerning the 'degree' of external confirmation' (pp. 23-25).

Einstein used the said criteria, above all, in tackling the question: can classical mechanics serve as the basis of physics as a whole? "External justification" for it becomes questionable in optics. First of all, the mechanical pattern of ether was in contradiction to the facts. The history of the theory of ether culminated in finally discrediting the mechanical models of ether. Maxwell's electrodynamics and Hertz's experiments which confirmed it were the decisive argument to shake the traditional appraisal of mechanics as the basis of physics.

The mechanical interpretation of Maxwell's electrodynamics became increasingly difficult as the processes in which weighable masses took no part proved to be the objects of electrodynamics. At the same time such an interpretation became less and less fruitful.

"... thus mechanics as the basis of physics was being abandoned, almost unnoticeably, because its adaptability to the facts presented itself finally as hopeless since then there exist two types of conceptual elements, on the one hand, material points with forces at a distance between them, and, on the other hand, the continuous field. It presents an intermediate state in physics without a uniform basis for the entirety, which although unsatisfactory is far from having been superseded" (p. 27).

The main substance of the definition of Newton's mechanics in Einstein's *Autobiography* is related, however, to the criterion of "internal perfection". Here the target of criticism is supplied by the basic conceptions of The *Mathematical Principles of Natural Philosophy*. As a matter of fact, the criterion of "internal perfection" is related to the initial precepts of the Theory and the special case, motion by inertia, cannot be singled out in this case. If we recollect what Einstein said about the criterion of "internal perfection", we understand why it is applied to the principles of the theory of motion in a general case, *i.e.*, the theory of accelerated motion.

Newton associates accelerated motion with absolute empty space and perceives proof of the absolute nature of accelerated motion in the appearance of inertial force. Let us remind the reader the lines from the "Principles", which outline this conception.

"The effects, which distinguish absolute from relative motion are, the forces of receding from the axis of circular motion. For there are no such forces in a circular motion purely relative, but in a true and absolute circular motion, they are greater or less, according to the quantity of the motion. If a vessel, hung by a long cord, is so often turned about that the cord is strongly twisted, then filled with water, and held at rest together with the water; after, by the sudden action of another force, it is whirled about the contrary way, and while the cord is untwisting itself, the vessel continues for some time in this motion; the surface of the water will at first be plain, as before the vessel began to move: but the vessel, by gradually communicating its motion to the latter, will make it begin sensibly to revolve, and recede by little and little from the middle, and ascend to the sides of the vessel, forming itself into a concave figure (as I have experienced), and the swifter the motion becomes, the higher will the water rise, till at last, performing its revolutions in the same times with the vessel, it becomes relatively at rest in it. This ascent of the water shews its endeavour to recede from the axis of its motion; and the true and absolute circular motion of the water, which is here directly contrary to the relative, discovers itself and may be measured by this endeavour. At first, when the relative motion of the water in the vessel was greatest, it produced no endeavour to recede from the axis: the water shewed no tendency to the circumference, nor any ascent towards the sides of the vessel, but remained of a plain surface, and therefore its true circular motion had not yet begun. But afterwards, when the relative motion of the water had decreased, the ascent thereof towards the sides of the vessel proved its endeavour to recede from the axis; and this endeavour shewed the real circular motion of the water perpetually increasing, till it had acquired its greatest quantity, when the water rested relatively in the vessel. And therefore this endeavour does not depend upon any translation of the water in respect of the ambient bodies, nor can true circular motion be defined by such translations. There is only one real circular motion of any one revolving body, corresponding to only one power of endeavouring to recede from its axis of motion, as its proper and adequate effect: but relative motions in one and the same body are innumerable, according to the various relations it bears to external bodies, and like other relations, are altogether destitute of any real effect, any otherwise than they may perhaps participate of that one only true motion" (Sir Isaac Newton, *The Mathematical Principles of Natural Philosophy*, London, 1803, pp. 11-12).

The appearance of inertial force means that the basis of classical mechanics, the principle according to which acceleration depends on the interaction of bodies, has been disturbed.

By calling inertia a force, we have retained the connection between the acceleration of bodies (caused by acceleration of a system and proving the absolute nature of this acceleration) and the "force", but the latter no longer expresses the interaction of bodies.

By declaring the interaction of masses to be the cause of inertial forces, Mach wanted to save the basis of classical mechanics, the dependence of acceleration on such interaction. In essence, he came out against Newton's absolute space from classical positions. Einstein initially considered "Mach's principle" a substantial element of the general theory of relativity. Later on he changed this appraisal. In his autobiography he wrote: "Mach conjectures that in a truly rational theory inertia would have to depend upon the interaction of the masses, precisely as was true for Newton's other forces, a conception which for a long time I considered as in principle the correct one. It presupposes implicitly, however, that the basic theory should be of the general type of Newton's mechanics: masses and their interaction as the original concepts. The attempt at such a solution does not fit into a consistent field theory, as will be immediately recognized" (p. 29).

The above lines are of primary historic significance; they alone, regardless of the rest of the *Autobiography* contents, make it an important document of the history of science. Above all, the lines contain a summary assessment of Einstein's views on a highly important subject. It would be extremely significant task in compiling Einstein's scientific biography to trace the changes in Einstein's views on inertia as a function of mass interaction, and the connection between these views and cosmological ideas. As this has to do with the greatest physicist of the century, the task exceeds the limits of a scientific biography and assumes historical scientific importance. But the matter concerns not only and not even so much the history of the relativity theory. The definition of "Mach's principle" is linked with the historical interpretation of classical mechanics.

In each of his works on the general theory of relativity, Einstein criticized Newton's theory from the position of another theory which likewise proceeds from a pattern of masses moving in space and interacting on one another. Now Einstein approached the appraisal of Newton's mechanics from another, more radical position.

Further, Einstein pointed to other major defects of classical mechanics as a basis of physics from the view-point of "internal perfection" of mechanics. These include the existence of (1) the law of motion and (2) the expression for force or potential energy, each independent from one another. In classical mechanics, the law of motion is independent from the laws of the field. At the same time it is meaningless, unless the forces are predetermined. But the expression for force is chosen at random which is particularly aggravated by the requirement that the forces should depend on the position of the bodies, and not on their velocities. This requirement does not ensue in an unambiguous way from the principles of classical mechanics and is by no means self-evident. Conformity, unambiguous connection with the least number of initial principles, and the absence of any arbitrariness, all these criteria indicate that Newton's mechanics is devoid of inner simplicity and naturalness. Arbitrary for classical mechanics is also the potential function $1/r$ which determines the action of gravitational forces and forces of electrical attraction to and repulsion from a point mass or point charge which set up corresponding force fields. Einstein links this defect of classical mechanics with the idea of far action. The potential function $1/r$ in a central symmetrical solution of differential equation $\Delta \rho = 0$, invariant with relation to rotation. The potential function is not arbitrary if it results from some law which points to its distribution in space. But such a law cannot be the initial principle of Newton's mechanics. It appeared as a description of real processes in a physical medium under the influence of facts and was directed against far action.

The above defects of classical mechanics, like the others specified further in Einstein's *Autobiography*, disturb its "internal perfection". Whereas for special theory of relativity another criterion ("external justification") was of primary importance, with the further expansion of the theory, its changeover to the general theory of relativity, the criterion of "internal perfection" *i.e.*, simplicity, naturalness and unambiguity, played a major euristic rôle.

The historian's important task is to clarify the real meaning of this criterion. By thoroughly examining it, we are able to note some analogy between Einstein's scientific method proper and his historical-scientific method as formulated in the *Autobiography*.

If one is to determine Einstein's scientific method proper, it may be called the method of invariants. The relativity theory meant a great triumph of the method, and the further development of this theory pointed very distinctly to the rôle of invariant analytical conceptions in its inner structure. Einstein strove to express the objective regularities of nature by means of magnitudes invariant as to co-ordinate transformations.

The same tendency, directed towards the past, underlies Einstein's historical-scientific method.

Simplicity of a theory is the criterion of its truth. What there does the word "simplicity" mean? It can be easily perceived that Einstein does not adhere at all to the old criteria of "simplicity" according to which nature functions. The case in point is that in its development the pattern of the world becomes devoid of anthropomorphous ideas and expresses the objective reality by increasingly objective methods independent, notably, from the methods of measurement, invariant as to the selection of methods of measurement and the "reference" systems. This, likewise, is what the condition of "naturalness" comes to, and, quite clearly this time, the condition of excluding arbitrariness in deriving conclusions from the initial premises.

It goes without saying that the above remarks about Einstein's historical method and the assessment of classical mechanics refer to but a small part of those numerous and profound historical-scientific ideas which the *Autobiography* contains together with the proper physical ideas.

MINIATURE SUN CREATED BY PLASMA "PINCH"

THE photograph taken in one ten-millionth of a second, shows a miniature sun created by a plasma "pinch".

The plasma, a very hot deuterium gas whose atoms are stripped of their electrons is "pinched" inward toward the centre of the tube. As it is "pinched", it is also compressed and heated to several hundred thousand degrees—hotter than the surface of the sun—and glows brightly. The streaks of light are longitudinal views of the pinch reflected by mirrors.

Such photographs reveal plasma instabilities and eventually make possible a controlled fusion reactor.—(*General Atomic Division, General Dynamics Corporation.*)