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THE RATIONALISM OF LEONARDO DA VINCI AND THE DAWN OF CLASSICAL SCIENCE

The fundamental concept of classical science is the differential representation of movement. Classical science studies movement between two points or between two instants of time. Peripatetic physics is based on a static scheme of natural positions, and it only considers movement from the point of view of its limiting points. Its theory of movement does not take account of the local state of moving bodies at every intermediate point of their path. Classical science, on the other hand, deals with instantaneous local states, which, in the special case of a body left to itself, do not change; in the general case, the interactions of bodies consist in acceleration that is proportional to the force applied. Thus, the basic concepts for classical science are the

Translated by Nicolas Slater.

https://doi.org/10.1177/039219217001806901 Published online by Cambridge University Press

limiting relations between the distance traversed and the time taken, and between speed and time; and these lose their meaning in the absence of an integral concept of moving bodies. Classical science appeared when the differential concept of movement became a system of differential laws, and found its essential mathematical formulation in the infinitesimal calculus. There had already existed a vague and unformed concept of a unitary local event, state, or relationship, which could be subjected to scientific analysis to the extent that it was conditioned by preceding events, states and relationships and itself determined subsequent ones. This concept had not yet been connected to the study of movement, it was sometimes applied to areas very remote from mechanics, while at other times it approached very close to physics, mechanics and mathematics, to the ideas of classical science. It approached very close—but it had not yet entered into these ideas. This was the dawn of classical science.

This was the dawn of classical rationalism, which proclaimed the sovereignty and omnipotence of the human intellect. During the Renaissance rationalistic tendencies were a feature of many philosophical movements which were widely separated by their content, their origins, and their subsequent evolution. Nonetheless there is a common idea that can be distinguished here. It could be called the rationalist tendency, the dawn of classical rationalism or even the rationalism of the Renaissance. The point is that the classical rationalism of the 17th century unites under one name some very different and in many respects mutually antagonistic concepts. Spinoza's rationalism is more different from that of Descartes than either is from the rationalistic ideas of the Renaissance. It is this that permits us to extend the term 'rationalism' to the ideas of Leonardo da Vinci.

The search for an objective *ratio*, an objective harmony and order, a cosmogony, for that which transforms chaos into cosmos, played a paramount role in the genesis of classical science. Human thought has always posed itself the question which was so clearly expressed by Einstein: "The most incomprehensible thing about the universe is that it is comprehensible." Why is it comprehensible, why is it amenable to logical analysis? It is just this question that has led scientific thought away from the empirical world of unitary realities and the *a priori* world of non-material abstractions. It is on this path that rationalism becomes a science. In the period with which we are concerned here, it becomes *classical* science. The rationalism that seeks for an objective *ratio* of the universe, that explains why the world is open to rational and logical knowledge, why (to use another aphorism of Einstein's) "God is subtle, but not malicious," has become embodied in the differential concept of movement. A very important question in the genesis of classical science, although a private one, was the question: "why is the universe accessible to *mathematical* thought?"

In the 16th century Giordano Bruno saw in the particular a reflection of the general, a reflection of the infinite soul of the universe. The particular becomes infinitesimally small when juxtaposed to the infinitely large Universal, but the particular does not disappear, it keeps its reality, indeed it gains in reality by reflecting infinite nature—its *ration*, its (and here we are putting new wine into old skins) "soul." The particular acquires reality, by becoming an element in an ordered process; local existence is real, because it is characterized by an infinite number of applications of the universal law; and this law itself acquires a physical sense when it is realized in infinitely small local relationships—i.e. when it becomes a differential law.

This is the latest, seventeenth-century equivalent of the path towards the understanding of the *ratio*—the path followed by Bruno in the 16th century. What were his antecedents, what path did Leonardo take towards finding the *ratio* in the 15th century?

Paul Valéry in his brilliant piece on "Leonardo da Vinci and the Philosophers" (1929) says that the concept of purely local criteria of science stands opposed to beauty, which is independent of time, place, and local criteria.[1] This aesthetic criterion has come over into science; the invariance of beauty has become the invariance of truth, of general laws. For Leonardo, beauty consists in the extension of the individual, its development into the universal, which is a spacial and temporal development. It is even more characteristic of Leonardo that he saw in this spatio-

[1] Paul Valéry, "Léonard de Vinci et les philosophes," *Divers essais sur Léonard de Vinci*, Paris 1938, pp. 127-128.

temporal extension of the individual something common to art and science.

Leonardo's physics is a qualitative physics; it does not deprive the universe of qualitative definitions, as do geometry and arithmetic, which "extend only to the knowledge of continuous and discrete quantities and are not concerned with quality, which constitutes the beauty of the works of nature and the glory of the universe."[2]

The evaluation of mathematics was closely bound up with the character of the rationalist tendency. The *a priori* rationalist tendency led to a concept of mathematics as a super-sensory schema, preceding physical existence. The rationalist tendency which led to classical science saw in physical existence, in the movement of particles, a real prototype of mathematical analysis. Leonardo was a representative of this tendency which was aimed at the future, at classical science and the differential concept of movement. Mathematics was for Leonardo, in the words of G. de Santillana: "not a contemplation of the super-sensory world, but a search for the geometrical framework of reality."

What is the relationship between Leonardo's and Descartes's physics? Paul Valéry says that Leonardo's words: "mechanics is the paradise of the mathematical sciences" expresses a pure Cartesian thought. In Valéry's opinion, the idea of an animal-machine is expressed more vividly and more clearly by Leonardo than by Descartes. "The search for knowledge through the automaton, through construction, was dominant in Leonardo."[3]

Leonardo is indeed bound to Descartes by direct links of succession. But here lies not only their similarity but also their difference. Succession is here a historical matter, and each of the thinkers preserves his historical uniqueness. Leonardo's early rationalism with its sensual accompaniment leads to a mechanistic explanation, but this mechanics is by no means the same as the geometrical Cartesian mechanics of uniforms bodies indistinguishable from their spatial positions. It is a mechanics of heterogeneous bodies endowed with qualitative differences.

[2] *Treatise on Painting*, 17.

[3] G. de Santillana, "Léonard et ceux qu'il n'a pas lus," *Léonard de Vinci et l'expérience scientifique au seizième siècle*, Paris, 1953, p. 44.

And so, when Leonardo's painting turns into mechanics, physics, philosophy, when it becomes knowledge of the universe and of its *ratio*, it does not cease to be painting.

"Leonardo is a painter: *I should say that painting is his philosophy...* he regards it as the ultimate goal of the efforts of a universal intellect."[4]

Leonardo's attempt to see the many-coloured universality of existence with all its qualitative attributes preserved has lead many people to compare his world-view with that of Goethe. In particular, Cassirer said that, for Leonardo as well as for Goethe, "the limits of vision are also the limits of achievement. Thus, the world that he can grasp as an artist and as a researcher is always the world of vision, but this world must stand before him not as a discrete and fragmentary phenomenon but in all its systematic fullness."[5]

But was the limit of vision really the limit of achievement for Leonardo? It certainly was not as much of a limit as it was for Goethe. After all, mechanical and mathematical methods of knowing nature were within the boundaries of Leonardo's achievement.[6] Goethe's "visibilism" is a protest against the universality of mechanical and mathematical cognition. Leonardo's "visibilism," on the other hand, is the very dawn of this sort of cognition, at a stage where it is still not clear-cut, where it still retains qualitative nuances and distinctions, and the new science has not yet juxtaposed to it Descartes's monochrome picture or Newton's even more uncompromisingly monochrome design.

Leonardo's pre-Cartesian rationalism lacked the basic gnoseological criterion of Descartes—*the criterion of clarity.* In the 17th century this criterion meant that objects of cognition could be given verbal expression (and in particular, symbolic-mathematical expression) of any desired degree of precision. If we not only designate an object or a property of it, but also *name* it, the object or the property lose their uniqueness and become objects

[4] *Divers essais...* cit., p. 152-3.

[5] E. Cassirer, *Individuum und Kosmos in der Philosophie der Renaissance*, Leipzig-Berlin, 1927, p. 167.

[6] Luporini, *La mente di Leonardo*, Firenze 1953, p. 153-4; V. Zubov, *Leonardo da Vinci*, Moscow 1961, p. 204.

of classificatory and therefore conceptual thought. But in Cartesian philosophy and, in general, in the rationalist philosophy of the 17th and 18th centuries, they lose not only their uniqueness but also their colour. Leonardo preserves the colours; painting has become a philosophy for him, without ceasing to be painting. But how then can one go beyond the limits of the unique?

Leonardo replaces the criterion of clarity by that of distinctness. Or rather, he does not replace it but anticipates it: the criterion of distinctness precedes that of clarity. Reason here operates by qualitative definitions, and its cognitive power depends on the perception of subtle qualitative nuances. To emphasize this point: it is *reason* that operates by qualitative definitions. The quantitative-mathematical rationalism of Descartes must not be allowed to obscure the qualitative-rationalist tendencies of Leonardo, for whom the distinctness of a nuance has become a tool of reason. As an artist Leonardo uses very fine nuances. Such subtlety was of vital importance for him. In his own words, the mind of a painter is like a mirror—it is transformed into as many colours as there are in the objects before him.[7] But what is a painter supposed to express with the help of this unlimited number of nuances?

We have here the principal task of Leonardo's paintings (which was for him the principal task of philosophy). It consisted in passing beyond the bounds of the particular and making the particular an element of the universal. This task looks forward to the future, to the 17th century, to classical science; for the extension of the particular is far from being the same as its logical subjection to some *a priori* integral scheme. The process takes place in time and space. Hence a logical generalization becomes a spatio-temporal one. Unity in diversity becomes a state of identity in the presence of various spatio-temporal predicates. True unity in diversity is the identity of a body with itself where it is endowed with various spatio-temporal predicates. Unique events correspond to the existence of a body in various places at various moments. Self-identity is guaranteed by the continuity of this series of places and moments—the continuity of movement of the body. Thus we see, if not a direct then at least an

[7] *Treatise on Painting*, 56, 58a.

https://doi.org/10.1177/039219217001806901 Published online by Cambridge University Press

uninterrupted line of succession between spatio-temporal generalization of the unique and the differential concept of movement, or classical science.

Leonardo considered that the advantage of painting over poetry was its ability to depict objects and events coexisting in space. This is not merely a matter of putting onto one canvas objects occupying different positions. The whole system of colouring, perspective, background, *chiaroscuro*, the representation of transparent and semi-transparent media, must demonstrate the bond between the individual and *spatial diversity*. But Leonardo goes further. He wants painting to pass from the unique, the sensual, the individual, to *temporal diversity*. This transition opens up the objective *ratio* of the universe.

For Leonardo painting is a philosophy because it "treats of the movement of bodies and the speed of their movement, while philosophy is also concerned with movement."[8] He goes yet further. He considers that painting and philosophy both have as their object a change of movement, i.e. acceleration. It was only one and a half centuries later that acceleration came to be regarded as a basic process of the universe, while velocity was treated as a steady state. It is clear that Leonardo's painting is not static but dynamic. But Leonardo's dynamism is not only embodied in his practice as a painter. It is embodied also in his *Treatise on Painting*, where he writes: "Painting is a philosophy, for philosophy treats of increasing and decreasing movement (*moto aumentativo e diminutivo*)."[9]

V. Zubov compares Leonardo's position with that of Lessing.[10] In his *Laokoon* Lessing says that the painter picks out one moment in a succession of moments and fixes it. Leonardo considers that the task of painting (and of philosophy!) is to seize not a static instant but a dynamic process. Zubov says of Leonardo's position:

> Let us then sum up once again: "instantly" (*in un tempo, a un medesimo tempo, in un subito*)—all this is not a moment snatched from the stream of time. It is an "instantly" which

[8] *Treatise on Painting*, 9, 3.

[9] *Ibid.*, 9, 1.

[10] V. Zubov, *op. cit.*, p. 320.

> presupposes a "before" and an "after" i.e. it regards time as a means of grasping the living flow of reality. After all, life is only possible where there is a "before" and "after," and where there is a link between "before" and "after." In other words, time is not only a "destroyer of things," it is also the necessary condition of their true life.[11]

Let us try to translate this concept into the language of modern science. Not in order to bring Leonardo closer to modern science and make of him yet again a "forerunner." But in order to characterize the historical uniqueness of Leonardo we have to apply to him himself the criterion of the link between "before" and "after." "Time as the condition for the true life of things" is expressed in the impossibility of the real existence of things outside their links with universal relationships which determine the behaviour of each thing. For each body, this interrelationship is expressed by the forces acting upon it, and its behaviour by its velocity and acceleration at a given instant. This sort of idea received its classical form in the guise of mechanico-geometrical interrelationships. The mechanics of Lagrange became the classical expression of this view of the universe. But we must not bring the differences between Leonardo and the classical form down to the level of a negative definition.

For Leonardo, the idea of a link with the universal as a criterion of the physical existence of the individual event had still not received this abstract and precise form. His conception was an early antecedent not only of eighteenth-century science, but also of later classical science. In the 19th century the abstract mechanics of Lagrange acquired a more concrete equivalent in the concept of the *field*. One must not therefore only juxtapose the ideas of Leonardo with the mechanico-geometrical schema. The most characteristic feature of classical science is not this schema but a rather broader idea.

It consists in the physically intelligible link between a separate body and other bodies, a link which determines the behaviour of the body according to differential laws. The further deciphering of Leonardo's idea, his "philosophy that treats of changes

[11] *Ibid.*, p. 322.

of movement" corresponds to the concept of a field determining the behaviour of a body. Such a meaning is connected to historical retrospection on the idea of the field. Paul Valéry in his *Introduction to the method of Leonardo da Vinci* (1894) says that with Leonardo, explanation has not yet become measurement, but he presumed a concrete, physical link between phenomena. "It appears to me," Valéry continues, "that for three centuries after Leonardo's death this method failed to be recognized, but everyone made use of it."[12]

Valéry goes on to say that forces acting at a distance do not correspond to this presumption of classical science. They were given analytic form, but Newton realized the inadequacy of the concept of action at a distance as an explanation of observed phenomena.

To this one might add that instantaneous interaction and hence the concept of absolute simultaneity contradicted the ideal of classical science, the explanation of phenomena in terms of interaction not only in space but in time.

Valéry says that only Faraday returned to the criterion of the physical representability of interactions. "It was less to Faraday to restore the method of Leonardo in physics."[13]

In connection with this Valéry quotes the well-known lines of Maxwell's preface to the *Treatise on Electricity and Magnetism*: "Faraday saw with his mind's eye lines of force traversing the whole of space, where mathematicians saw centres of force exerting attraction at a distance; Faraday saw a medium where they only saw distance."[14]

To consider Leonardo as a "precursor" of Faraday would mean not only losing the sense of historical uniqueness of the events in the history of science, but also losing one's sense of proportion. Valéry's juxtaposition has another sense altogether. It becomes clearer if one returns to the evolution of rationalism.

Reason, which can grasp the objective *ratio* of the universe, cannot limit itself to individualities. Aristotle said: "If nothing exists apart from particulars then nothing could be grasped by the

[12] Paul Valéry, *op. cit.*, p. 112.

[13] *Ibid.*, p. 112.

[14] *Ibid.*, p. 112.

intellect, and everything would be merely an object of sensation, and there would be no sciences unless perhaps someone were to say that sensation was a science."[15] The transition from the particular to the general was realized in an abstract geometrical form, which was often made absolute by giving an *a-priori* meaning to abstract concepts. At the same time scientific philosophical thought sought to find a representable mechanism of interaction between individual bodies—that is, a mechanism possessing analogies in sensually perceptible processes; either direct analogies, as with Faraday, or conditional ones, as with Maxwell. The concept of a physical field in the works of Faraday and Maxwell was in a sense a synthesis of a model and an abstract concept.

Among the logical and psychological hypotheses of the "model-oriented" sensual side of rationalist thought of the 18th and and 19th centuries (one might put this more strongly and talk of the sensual *component*) there were traditions dating from the Renaissance, when, in the words of Valéry, "explanation had not yet become measurement." This tradition dates back even further, to the Nominalists of the 14th century, and even further. But the Quattrocento turned a narrow stream into a broad river. The art and technology of the Renaissance made people's thoughts about nature more objective, clear, colourful and "mode-like," and got rid of some traditional syllogisms. In the work of Leonardo art and technology were combined with a straight defence of concrete images as a method of rational cognition of the universe.

In our age it is possible to see more clearly and more deeply the logical "valencies" and historic steps linking the ideas of the past with the latest ideas of the present, and to see in these ideas questions addressed to the future including some as yet unanswered. In our time, the central problem of theoretical physics is that of the *existence* of elementary particles. Let us specify more precisely the concrete, modern, and specific sense —specific for the second half of the 20th century—given to this very general concept of philosophy—perhaps the most general of all.

[15] *Metaphysics,* III, 4, 999B.

We know a fair amount about the *behaviour* of elementary particles in relatively large spatio-temporal domains (by comparison with the sub-nuclear scale, say 10^{-13} cm and 10^{-24} sec). This behaviour—position, velocity, acceleration—is described by the universe lines of the particles. But we know almost nothing of the nature of such properties of these particles as their mass and charge. These properties distinguish one type of particle from another. Moreover, it is these properties that distinguish matter (what Democritus calls "being") from space (what Democritus calls "not-being"). We have reason to believe that the difference that exists between the universe line and its geometrical image, between a particle and its four-dimensional localisation, is the result of a process of transmutation which transforms particles of one type into particles of another type in spatio-temporal cells of the order of 10^{-13} cm and 10^{-24} sec. But here we come up against a very paradoxical situation. The macroscopical behaviour of elementary particles loses its physical sense (it cannot be found experimentally) without ultramicroscopical transmutations. But these latter lose their physical sense without macroscopical behaviour, because a change of type of a particle and its very type itself can only be determined by the form of the universe line of the particle. A change in the type of a particle, a transmutation, is a transition from one potential universe line to another. The complementarity of local transmutations and macroscopical universe lines is a new form of the old complementarity of the individual and the universal. Classical science attributed a potential movement, velocity, and acceleration to a particle at a given point, determining its movement with a point, obtaining limiting values and relating them to the interactions of particles, to fields of force. Science assimilated this method in the 17th century. In the preceding century Giordano Bruno saw the true existence of the particular as a reflection of the infinite Universe, and in the 15th century Leonardo, uniting aesthetic with gnoseological criteria gave the individual a potential way out into the universal, into spatial and temporal diversity.