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THE VALUE OF SCIENTIFIC ERRORS AND THE IRREVERSIBILITY OF SCIENCE

1. The criteria of truth

Non-classical science gives a very specific answer to the question of scientific errors and their epistemological value. But for all the specificity of this answer, it casts light on a problem that remains with us century after century, the historically constant problem of truth and error—one of the most fundamental problems of knowledge. At first sight, these two poles have always stood opposite each other, like good and evil, beauty and ugliness. But moral and aesthetic theories have long since left behind this initial conception, and shown that the two polar concepts are in fact inseparable. As regards truth and error, their indivisibility has only become apparent in the context of non-classical science. Truth has ceased to be the absolute contradiction of error. Contemporary science finds it to be something relative, inseparable from its opposite pole. But the non-classical, retrospective approach, a re-evaluation of the past of science in the light of its present, and indeed even more in the light of its prognosis, its future, allows one to see that scientific truths

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that are adequate for the object of knowledge always reflect only one side of the objective world, a world which has an infinite number of sides. The irreversible process that leads from relative error to relative truth has an absolute character: an irreversible process of generalization, concretization and complication of a *Weltanschauung* that more accurately reflects the infinite complexity of life.

All this, as we have said, became apparent in non-classical science. *Apparent*, that is, in the sense of a direct confirmation by the very content of scientific theories. But even before this, in the philosophical generalizations of classical science—and even earlier, in ancient philosophy—as soon as the *evolution* of truth was taken into account, it became indivisible from error and acquired the character of a movement from error towards truth—a movement infinite in extent. Science could not develop if truth was regarded as something definitive, a sort of truth of last resort. Nonetheless, in the past, fundamental truths have changed so slowly that every particular truth appeared static, and was, in a sense, quasi-static, if it was incorporated, without contradiction, into a general system of ideas about the world. Descartes was not worried by the artificiality and indefiniteness of his particular kinetic models; he (and even more so his followers) regarded their models as true and adequate representations of fact, if they illustrated the general ideas of his physics. Newton introduced into science the principle of the univocality of particular truths, but in spite of the inductivist formulae of his "Scholia" and "Principia", he required them to correspond with general principles. When brought together, the particular truths became integrated into a general conception of the world, like pieces of a mosaic that go to form a single picture. Today's conception of the world is more like a picture on an easel, where almost every new significant brush-stroke changes the whole color-scheme, the lighting, the composition. It is no longer the stability of the world-picture but the degree to which its transformation approaches the irreversible process of evolution, that is one of the fundamental criteria of the truth of each element of the picture. Hence the change in the very concept of truth, and consequently of the concept of error. When Chevreul, after his centenary, was drawing up the balance-sheet of his creative life, he said that his motto was "Always to strive for truth, and never to claim it". This motto of a thinker, who started his life in the 18th century and continued to work into the 1880's, ("Child of the Age of Reason", Timiryazev said to him at his centenary jubilee, "You have become the living incarnation of the century of science")— this motto is prophetic; it has been realized with unparalleled clarity in the 20th century. Non-classical science has likened the striving for truth, the approach to truth (an irreversible approach!), with truth itself, which lays no claim to any definitive character.

The concept of truth has changed together with its content. "Truth is the daughter of time" is true not only of the content of truth, but of the idea of truth itself. In the context of peripatetic scientific thought, the content of the most general physical and astronomical truths was the static harmony of the universe. But the concept of truth itself was also static. Because the qualitative evolution of the universe was ignored, the path towards radical changes in knowledge, and in the concepts of truth and error themselves, was closed. In the Middle Ages, these concepts were fixed in the official ideology by the antithesis between canonized truth and non-canonical error. The Renaissance gave these notions a litttle more of a relative character. Raphaël's "Schools of Athens" is an apotheosis of diversity of opinions, pluralism of truth and relativity of error; in contrast to Andrea di Firenze's fresco "The Apotheosis of St. Thomas Aquinas"—still a mediaeval work in this respect—in which pagan philosophers and heretics are together trampled underfoot by the representative of canonized truth.[1] For Renaissance thinkers, errors meant not merely views that were not in accord with experience, but also views that led away from science, away from heterogeneous truth, towards homogeneous dogmatism. The maxim "Truth is one, but errors are many", i.e., the idea of the uniqueness of truth, had already lost its medieval

[1] See A. K. Gorfunkel, "From 'The Triumph of Thomas' to 'The School of Athens'", in *The History of Philosophy and Questions of Culture*, Moscow, 1975, pp. 131-166; B. G. Kuznetsov, "Reason and Being", Moscow 1972, p. 75; *History of Philosophy for Physicists and Mathematicians*, Moscow, 1974, pp. 179-180.

sense, but had not yet acquired a new, experimental, logico-mathematical sense, appropriate to the modern age.

In the 17th century, both Descartes and Newton were apostles of the uniqueness of truth and the multiplicity of errors. Descartes laid stress on what Einstein called *inner perfection*, i.e., on the logical deduction of particular theories from a general principle. For Descartes, error is that which contradicts kinetic presumption. Newton stressed *external verification*: for him, the difference between truth and error is empirical; error is that which contradicts experience.

Nineteenth-century science introduced a new criterion of truth and error. For classical thermodynamics and for statistical conceptions in general, the distinction between truth and error is an essential one in the context of the macroscopic representation of phenomena. In the theory of errors, errors are statistically cancelled out. When we move from the position and motion of particles to their probability, their positions and motions acquire reality in a reliable macroscopic picture. This criterion of the *essential* nature of truths and errors is converted into an error of principle, when the difference between the macroscopic and microscopic worlds acquires absoluteness, and when ignorance of the fate of particles becomes a denial of them. Altogether, nineteenth-century science saw the appearance of the concept of *errors of principle*. This means the negation of the relationship between the existence of the microscopic world and the laws of the macroscopic world, or else the negation of the specificity (and in particular, the irreversibility) of the processes of the macroscopic world. The concept of an error of principle means that the dichotomy of *truth - error* is applied no longer only to the content of ideas, but also to their vectorial sense; the dichotomy refers to the direction of ideas, to the course that a particular idea selects. The choice of the epithet "true" or "false" is determined by a gnoseological prognosis and evaluation of how close the path taken by the idea in question lies to the true, irreversible path of knowledge. But at the same time the dichotomy acquires a metrical sense: the closeness of the idea to the "true", irreversible path (one might say "the cosine of the angle between the two paths") may be of any size.

The new criteria of truth and error introduced in the 19th century were developed and brought to a much clearer form in the 20th. The whole history of the theory of relativity, beginning with the ancient relativity of the ideas of "up" and "down", is the history of plurality of truth and relativization of error. And yet at the same time, it is the history of the uniqueness of truth and the absolute nature of errors. Such a contradictory conclusion demands some explanation.

Starting with Einstein's theory of relativity, the exposition of relativist ideas is often carried on in the form of a question: which observer is in the right and which in the wrong, when each of them ascribes to himself a state of rest or of motion? It follows from the principle of relativity that each observer is right or wrong depending on the system of reference to which the concepts of rest and motion are related. In essence, the discussions about the antipodes falling "down", and other discussions that eventually gave rise to the idea of isotropic space, probably incorporated collisions between the error and the truth of the opinions of different observers. Similar collisions are reflected in arguments about geocentrism, and culminate in the theory of Einstein. This was the culmination of a long-lasting trend towards pluralizing the truth and relativizing error. But at the same time the observation of a state of rest or motion became a unique truth when related to a given system of reference, and such an observation when related to a space devoid of material bodies became absolutely erroneous. In essence, then, there was here, too, a collision between the local *here-and-now* and the integral *outside-the-here-and-now*.

This collision became even more apparent in the quantum-mechanical concept of truth and error. The transition from probability, that indefinite synthesis of real and possible observations, to certainty, i.e. the transition from the plurality of truth and relativity of error to unique truth and the absolute error of other observations, takes place here not in a statistical totality of particles, as in classical statistics, but in relation to the local *here-and-now* of the situation and to the individual particle. But this transition is realized in the context of the wave-particle dualism, in which a particle is defined as the midpoint of a wave-field. Probability waves are the inclusion of potential errors into the true representation of *here-and-now-being*. Experiment, the interaction of the quantum object with the classical apparatus, is a transition from potential errors to certain truth.

Science in the second half of the 20th century has drawn from its two chief historical sources—the theory of relativity and quantum mechanics— both the first and the second method of passing from the plurality of truth to a unique truth: both the inclusion of definite systems of reference, and the transition from a pluralistic "wave" definition of conjugated variables to a univocal "particle" definition. This implied a fusion between macroscopic truth, related to the All, and microscopic (or even ultramicroscopic) truth, related to local elements of being. Such truth is related to being in its homogeneity and heterogeneity; it is a genuinely philosophical truth, but a physical truth for all that.

Thus the concept of scientific truth has evolved from a limited truth related to local observations, a microcosm, or else from a purely macroscopic truth, to a truth that is all-embracing and univocal. Scientific truth has come closer to what is demanded of a witness in a law-court: "the truth, the whole truth, and nothing but the truth". This is the meaning behind the fusion, so typical of 20th-century science, between the criteria of external verification and internal perfection.

There has been a parallel change in the concept of error, deviation from truth, and the attitude taken to such a deviation. The style of the conversion from error to truth has changed. For the Middle Ages, a typical attitude consisted in likening error to heresy. An evaluation of truth and error took the form of official canonization and apologias for the former, and anathemas, or later an inquisition, for the latter. Both truth and error appeared to be something very personal—a necessary levelling of the personality in the former case, or its sinful autonomy in the latter. During the Renaissance both truth and error remained characteristics of humanity, but they exchanged roles: canonized truth appeared as error, a straying, an offense against Reason, while the manifestation of the personality appeared as a truth. Of course, we are speaking here only about one trend—there were plenty to oppose it. But such a trend was new and characteristic; it marks out the style of value-judgements in the 15th-16th centuries from that of earlier times.

In the 17th and 18th centuries, both Cartesianism and Newtonism relied on the idea of a single, uniquely defined truth. Consequently there could only be one reaction to error: it was cast away from the threshold; and in so doing, the Cartesians, as they rejected views foreign to them as erroneous, appealed to a-priori arguments, while the Newtonians appealed to experiment. In the 19th century, the position changed. The world turned out to be heterogeneous, truth also turned out to be heterogeneous, and erroneous assertions usually consisted in the extension of specific laws governing one series of phenomena to another series, i.e. in the forgetting of the irreducibility and specificity of phenomena; or else in the ignoring of that which relates together different series of phenomena. Elementary errors increasingly seemed to belong to the past, or rather they became short-lived mistakes; the precision of experiment increased quite fast, and experimental activity itself acquired an increasingly continuous character. There was therefore not long to wait for increased precision in the results obtained. Errors of principle gave rise to lengthy discussions, but here too decisive experiments were sooner or later performed and settled the problem one way or the other.

In the first half of the 20th century the accent fell onto a different criterion of scientific research. The theory of longitudinal contraction proposed by Lorentz did not contradict experimental data, but it was an ad-hoc theory, which did not follow on from broader principles and did not have internal perfection. In the second half of the century the concept of error became very conditional, and the value of "errors" (quotation marks are usually essential now) appeared to be very high indeed.

Thus, starting in the 17th century, or even with the Renaissance, the concept of scientific error has been very radically transformed. Finding an error increasingly implies circling round a concept and defining its field of application, outside which its application is an error. In consequence, the style of polemics in which a particular theory is conceded to be erroneous also undergoes a change. Norbert Wiener once said that the problem of evil can be solved either by following St. Augustine's path—evil as something rather like entropy—or that of the Manichaeans—evil being personified, and responsibility for it ascribed to some evil spirit. If, with all necessary reservations, one applies this sort of dichotomy to scientific error, then the evolution of this concept goes from the Manichaean version to that of St. Augustine: error becomes indivisible from truth, and can even be increasingly likened to the variations that define the curve of truth. In discussing scientific errors, scientific polemics inevitably approach the tone of Plato, defined by Hegel as one of "Attic worldliness", and founded on criticism as a way of completing, generalizing, concretizing, limiting, and outlining the "field of application" of an erroneous idea; founded, too, on the search for a fragment of the irreversible evolution of knowledge that has served to bring the idea to life.

The change in the concept of truth and error leads to a particular historical and scientific aberration. Let us compare the first and the second halves of the present century with the first and second halves of the 19th. In the second half of the 20th century, we may seem not to have moved so very far away from the first. The speed of scientific progress has fallen; the revolution brought about by the theory of relativity and quantum mechanics is more radical than any changes seen in the 1950's to 1970's. In the 19th century, science in the years after Maxwell and Darwin made a much more radical departure from the ideas of the beginning of the century than was the case in our own century. This is because, in present-day science, the theories that we leave behind can no longer be regarded as erroneous; they remain merely more precisely outlined, but still as historically invariant principles of science.

2. Epistemological value

The problem of the value of scientific error, as applied to non-classical science, requires not only a new concept of *error* but also a new concept of *value*. Contemporary science, in the second half of the 20th century, is being subjected not only to gnoseological analysis, but also to axiological analysis—the analysis of the economic, social, moral and aesthetic value of science. The fundamental link between the science of the latter half of the 20th century and the evolution of the concept of value is a consequence of the fact that the connnection between the knowledge and the transformation of the world is much clearer now than it used to be. It is precisely this that has created the modern idea of a link between gnoseology and axiology. The gnoseological problems that follow from the generalizations of non-classical science, and particularly the science of the latter half of the 20th century, are indivisible from axiological problems, problems of value. The value of knowledge has become one of the most fundamental problems of philosophy, science and the whole of our present-day culture. In one form or another, it draws the attention of humanity as a whole; people wonder, with both hope and alarm, what influence science may exert on their fate.

The fundamental criterion—and more importantly, the fundamental definition—of the value of knowledge is the transformation of the world; and especially the *irreversible transformation* of it—the consistent growth of the part of the world that is turned towards mankind. The influence of mankind on the world is based on objective processes, some of which are reversible and some irreversible; on a proper assortment of such processes, on choice, on comparison, on a hierarchy of natural processes. This is by no means a subjective hierarchy; there are, in nature, objective differences between processes, which create the *possibility* of a proper choice and organization of them. If there were no temperature gradients in nature, then their flattening (by a process of increase in entropy) and their formation (by a process of increase in negentropy) would not exist either, and there could exist no rational combination of thermal processes; but the converse is not true—the existence of these processes does not depend on one's knowledge of them or on their proper application. To generalize the concepts of entropy and negentropy, and to introduce the concept of the destructuring and structuring of the world, one might say that there is in nature an *objective value*, positive or negative, and that the presence of such a hierarchy of objective values confers on knowledge a human, social value, as a component in the transformation of the world.

The transition from the *knowledge of value* to the *value of knowledge*, from the realization of objective value in nature itself to the effect of this sort of realization, and its effect on civilization—this transition encounters a fundamental snag. Henri Poincaré once formulated one aspect of this snag—the collision between scientific observations of what *is* and ethical pronouncements about what *should be*.[2] In his words, existence is the subject of observations, made in the indicative mood, while ethics are the subject of judgements in the imperative mood.

A value judgement is always an escape from one series of interconnected processes into the field of different processes, from one system into another. This is the general feature of value judgements. The value of knowledge is the reflection of the results and methods of science in other fields, in which statements about what should be—the "imperative mood" of Poincaré—have the right to exist. But even in science itself, criteria of duty find a place, as soon as we begin to regard science as an activity, a sphere of social performance, as the sum not only of observations but also of reasoned activity, the search for proofs, experimental checks, etc.—everything that man *must* do, in order to achieve this or that practical or cognitive result. Practical or *cognitive*—thus the issue is not one of the value of knowledge as the reflection of the content of science in a system of applied scientific results. Long ago, ever since the very beginnings of classical science, it has been possible to speak of the value of logic for mathematics or mechanics, of the value of mechanical models for physics, of the value of physical methods, concepts and schemes for chemistry, etc. It is worth stressing that the applicability of the concept of value in this sense has been the result of the structuring of science, the demarcation of specific disciplines, specific forms of movement, specific links, hierarchies of embracing and embraced systems of *being*.

In the 20th century, value-judgements and transitions from one series of processes, phenomena and ideas to another are part of science in another sense too: the value of general principles is defined by their effect on *external justification*, and the value of empirical tests is defined by their transforming action on *internal perfection*. This is by now a non-classical relationship between the value and the content of science: the dependence

[2] H. Poincaré, *Dernières pensées*, Paris, 1919, p. 225.

of the most general principles has become apparent in non-classical conceptions, in the theory of relativity and in quantum mechanics.

The value of knowledge is defined in prospect and in retrospect. One may speak, for example, of the value of Renaissance science, on the basis of the active influence it exerted on Baroque science, on the 17th-century world-picture. This reevaluation, and the sense it gives to the future, introduce into the content of science the concept of value which corresponds to the transforming part played by science in retrospect and in prospect.

This transforming role played by science is related to the value of its invariants, its continuing problems. The value of problems lies not in any particular positive solutions, not in the level of science, but in its dynamics, its temporal derivatives. In this respect, value is a reflection of positive solutions, in hypotheses, problems, questions, in the history of science seen as the history of its interrogatory component.

In all the cases cited, the issue is one of the reasoned action exerted by science upon itself, the effect of an observation (in the "indicative mood") on the choice of methods, the transfer of concepts and methods from one discipline to another, the direction of research, the character of the experiments that are devised, everything that is defined by the preliminary selection of a goal, everything to which the epithets "better" and "worse" can be applied; and with the help of these epithets, the task of research is formulated, and the concept of duty, the "imperative mood", enters into science. Its exclusion from science is the result of the limitation of science to a passive observation of the structure of the world. But knowledge cannot advance if it limits itself to this sort of observation; its dynamics are active, it includes action, and without this it cannot prove either the uniqueness of new observations, nor its general, consistent adequacy to objective reality. The history of science is the history of initiative, activity, action, effect, value. There is no shred of pragmatism here: value is determined by how close one approaches the truth, but the approach is seen as a task, from which knowledge cannot withdraw, as it keeps in view a continuing approach towards reality.

The value of knowledge to knowledge itself, the value of the content of science, its results, its observations, for research, its methods and experiments—for the basic conditions of research itself—make up the *epistemological value* of knowledge.

It follows from what has been said that the immediate value of scientific errors, their epistemological value, becomes a more general value—the value of scientific errors for civilization. What, then, is the epistemological value of errors and mistakes through which the infinite and irreversible progress towards absolute truth must pass?

Of course, we are not speaking here of subjective errors, which lie outside the evolution of knowledge. Niels Bohr is often quoted nowadays on the subject of Werner Heisenberg's theory of non-linearity: "this theory, undoubtedly, is insane, but is it sufficiently insane to be true?" This does not mean that insanity is a sufficient justification for a scientific theory. Similarly, the erroneousness of a scientific conception is by no means sufficient to include this conception in the historical evolution of knowledge. This concept of the "insanity" of contemporary science would be an error in the most elementary sense of the word, and would be devoid of any value. Where, then, is the boundary between errors that have no value and those that play a part in the evolution of truth similar to the part played by evil in the evolution of morality, or ugliness in the evolution of beauty?

This is a role that belongs to scientific errors which affect the character of the questions that science addresses to the objects of its study, viz. nature and human society. Every scientific assertion always contains some new question, some interrogatory component. The character of these questions changes, and at the same time certain pervading, historically invariant problems of existence, knowledge and value remain. They concern existence, its reflection in knowledge, and the value of this reflection. We are speaking here of existence as a whole, not of the sum of natural processes, not of Spinoza's *natura naturata,* nor of the totality of modes; but of *natura naturans*, nature as an integral whole. Every genuinely *scientific* error (as distinct from errors that go beyond the bounds of science) can affect the consistent and irreversible increase in complexity, concreteness and generality of the questions that science asks of nature.

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Let us recall once again the hypothesis of longitudinal contraction proposed by Lorentz to explain the invariance of the velocity of light in systems that are in motion relative to one another. This *ad hoc* hypothesis was wrong, and gave place to Einstein's conception, which was endowed with a high degree of internal perfection. But Lorentz's hypothesis as in essence a question addressed to nature; a question related to one of the fundamental problems of existence, and one which provoked an acceleration in the growth of knowledge; it therefore had epistemological value, and consequently also value for civilization.

3. The entropy of errors, the negentropy of truth, and veritas triumphans

Everything that has just been said about scientific errors has referred not so much to individual deviations from truth as to the very concept of error itself, and to the relation between this concept and the concept of truth. The conclusion to be drawn—the indivisibility of this concept from dynamic truth itself, truth as a process, as a search, as a substrate for the growth of knowledge—requires some additional comments. Error, as an element in the *evolution* of truth, consists (as we have said) in the unjustifiable transfer of specific laws of existence into a more general field; the unjustified transfer of a segment of knowledge to knowledge as a whole—a transfer that leads to the search for more general laws, to the generalization of the scientific view of the world, the fusion of the sum of modes, the *natura naturata of Spinoza*, with the integral view of existence, *natura naturans.* But this is a characteristic of error as an epistemological category. What, however, is the role and the value of concrete errors, having no pervading character, characterized by a short-lived "run", and laying no claim to the role of stages in the forward and upward advance of knowledge? What is the role of erroneous and subsequently corrected experimental data, of unconfirmed hypotheses, refuted conclusions, in short *mistakes* that do not have the character of a *straying* from truth? Can we ascribe any epistemological value, in the true sense of the phrase, to such mistakes?

They form a broken line in the "space of knowledge". It is a line that consists of random, directionally disordered movements of cognitive thought; something similar to the Brownian movement of particles that are subjected to random collisions with surrounding molecules. This analogy can be taken further. The random movement of molecules stands in contrast to the ordered process of transfer of heat from a hotter body to a less hot one. Thermodynamic order, the negentropy of the world, is in contrast to the growing disorder and entropy of isolated systems. But the macroscopic dynamics of thermal processes cannot be wholly separated from the microscopic world of disordered molecular movement. Without them, currents of heat would be a movement in the absence of that which moves—the idea would lose all physical meaning. An analogous situation obtains with respect to the individual, macroscopically and phylogenetically disordered variations of heredity (as they were considered in classical science), and the order represented by selection. In the practice of artificial selection, methods of "shaking up" heredity and increasing the dispersion of individual deviations have long been known. Their aim is to "upset" ("affoler") the process of heredity— a term hallowed by long usage. Of course, the entropy of hereditary differences would lead to an increase in dispersion, if the environment or applied genetics did not set new limiting conditions and thus lead to the "negentropy" of selection.

In the historic process of the growth of knowledge, the element of disordered scientific errors—the entropy of science—might have increased in an isolated system. But in science, the isolation of problems and of the methods of solving them are disrupted by the interference of concepts, principles, experimental methods, mathematical processes, which all set new preconditions and limiting conditions for the problem in question. In science as a whole, therefore, the dispersion of conclusions, observations and concepts—the entropy of knowledge—is not growing but diminishing. If one were to write the history of scientific errors, one would find that the starting-points for their conquest would be the migration of concepts, ideas and methods, the collisions between erroneous ideas and new experimental data, the abolishing of the isolation of a particular experiment or a particular theoretical construct. The history of mistakes would become the history of the development of truth, the history of *veritas triumphans.*

Just as the notion of entropy distinguishes thermodynamics from mechanics, so too in epistemology the existence of a disordered world of mistakes distinguishes the history of science from its rationalized logical scheme, *veritas triumphans.*

Here one must introduce a necessary clarification. The errors that create the entropy of knowledge, and that are therefore endowed with epistemological value, are infringements of non-trivial truths, which demand a confrontation with error, whose issue is not known in advance. Two assertions contend for the title of truth, and have this or that probability of victory in the contest (i.e. in the experiment which will turn probability into certainty). Assertions that have zero probability are trivial mistakes; assertions that are reliable *a priori*—i.e., that have maximum probability—are trivial truths. Non-trivial truths and errors have a probability of becoming certain truths lying somewhere between zero and unity.

4. The Collisions of truth and error

Thus, the value of scientific error consists firstly in the intensification of the interrogatory component of knowledge, the complexification, generalization and concretization of the questions addressed by science to nature; secondly, in that disordered world of errors that makes science into a real historical process, relating the logical substrate of developing science to concrete local issues. But there is also a third aspect of the value of errors, perhaps the most essential of all for fundamental research, for the search for new ideas about space, time, motion, matter and life. This is the conversion of that which was considered a mistake into a more precise, concrete, general scientific truth, standing closer to reality.

This is by no means merely a process of re-evaluation or of retrospective rehabilitation of errors. It is a transformation of the sense of an erroneous assertion, an alteration of a more general concept which was contradicted by the assertion in question. It is what Einstein referred to as the *flight from the miraculous*; the transferring of a paradox from an individual observation to a general conception. During the predominance of the peripatetic world-picture, the helioecentric view that stemmed from Aristarchus of Samos was held to be erroneous. It received its recognition in the 17th century. But at the same time the ideas of space, time and motion underwent a change. Inertial motion came to be considered a state not requiring the application of a force; the ideas of the homogeneity of space and the conservation of momentum were born. An even clearer picture is presented by the genesis of the theory of relativity. The denial of the aether in classical physics was considered an error. It turned out to be true when ideas of time and space were turned upside down. Even more indicative, perhaps, is the genesis of quantum physics, the fate of the particle theory of light, which after the appearance of the wave theory was regarded as an error. The rehabilitation of the particle theory took place on the basis of a transformation of the very distinction between the continuous, wave-like, and the particulate aspects of existence.

In this context great importance attaches to the existence of a period when an error ceases to be an error and no longer stands in opposition to truth, but to tradition; while at the same time it does not yet satisfy the criteria of truth—internal perfection and external verification. This intermediate stage between error and truth demonstrates the flexibility of the opposition between them, the plasticity of polar definitions, and the transition from one to the other. Most important of all, it demonstrates the connection between a transition of this sort and the transformation of the logic of existence and the world-picture as a whole. Collisions exist between *error* and *truth*, which become in their own way a sort of *collisio crucis*, analogous to the *experimentum crucis*, and which demonstrate the inevitability of a transition from one concept of error and truth to other concepts, and the relativity of these two poles of knowledge, their indivisibility from one another. This is the nature of the paradoxes of Zeno and Epimenedes, the antinomies of Kant, or Russell's paradox of sets.

Let me now make a few comments on the connection between the above paradoxes and the antithesis *error* - *truth*. In all these paradoxes, the verdict "true" or "false" is given in a conditional form: "Let us suppose that such-and-such an assertion is true, and such another is false"... In the paradox of measurement —Zeno's initial paradox—two assertions are under examination, relating to the extension or otherwise of the elements that compose an extended quantity. When the verdict "true" is applied to one assertion, and "false" to the other, we arrive at the impossibility of composing a finite quantity out of its elements: elements with no extension add up to a sum of zero, while elements with extension, being infinite in number, add up to infinity. The whole subsequent history of this and other similar paradoxes of Zeno, the whole evolution of the contradictions of infinity, has been a dialogue between truth and error, which has received the name of *dialogic*.[3] The same dialogue can be felt even more clearly in the paradox of Epimenedes: a Cretan pronounces the statement "All Cretans are liars"; if the statement is true, it denies its own content and becomes false, but if it false, then it confirms its own content and turns out to be true. This is a structural paradox: the issue concerns a system which enters into itself as one of its component elements. This has been developed in Russell's paradox: the set of all sets which are not members of themselves behaves in a very odd manner, in that if it is a member of itself then it does not belong to itself. This sort of turning of truth into error and error into truth demonstrates the relative nature of the division between them, and is actually a question, an impulse and a stimulus for even more radical transformations of the content and logic of science.

5. The irreversibility of being and knowledge

The transition from the verdict "true" to the verdict "false" is a reversible one; it may precede or follow the reverse transition. And yet scientific progress as a whole is irreversible: in the historical succession of scientific conceptions and their evaluation, there is an underlying irresistible process of approach between the world-picture and objective truth. What part, then, is played by erroneous judgements? Does any process of penetration into the reality of phenomena accompany even erro-

[3] See V. S. Bibler, *Thought as Creation (An Introduction to the Logic of Mental Dialogue)*, Moscow, Politizdat, 1975.

neous judgements about the character and causes of these phenomena?

This concerns what Reichenbach called the "*strong irreversibility of time*", i.e., the distinction between *before* and *after* which is recorded as a *now* at every moment of time. The problem lies in the asymmetry of knowledge, not only in the sense of a difference between epochs and periods, but in every step made by knowledge. Consequently we are dealing not only with epochal generalizations, but with local events in the history of science, with irreversible progress that is realized in every event, every new experiment and every new—albeit erroneous—idea. There is no need to recall yet again that we are speaking here of non-trivial truths and non-trivial errors, which are the only ones that can lay any claim to the title of events in the history of science.

Here we must make a short excursion from the realm of irreversible knowledge into that of irreversible being. The point is that the irreversible component of knowledge is an ever closer approach to the objective cosmic evolution which serves as a basis for the asymmetry of time. The more concretely science answers the question of the irreversibility of time, and the more precisely it relates the fundamental process of complication of the universe, the further goes the irresistible advance of the history of science, the irresistible evolution of ideas about the world, and the complication of our world-picture.

The idea of the irreversibility of time, in its turn, rests not only on thermodynamics, cosmology, the theory of relativity, quantum mechanics—but also on the concept of irreversible historico-cultural time, the irreversibility of scientific and cultural evolution and of social change. The sense of the irreversible flight of time, after all, affects man even if he knows nothing of thermodynamics; it is created as the integral generalization of all his observations and impressions related to nature, society, culture; and also as a generalization of his self-observation, his recording of his inner life, his thought and his knowledge.

If one limits the concept of truth and that of error to their non-trivial content, taking truth to mean that which is attained by constantly improved experiments and improved logical and mathematical constructs, and error to mean that which may be

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refuted only by the same means—then every step taken by science, irrespective of its evaluation, is accompanied by some elevation of intellectual and experimental potential, a "*z* co-ordinate" which increases independently of the direction of the step taken in the "*xy* plane", the plane of these or those positive conclusions and observations. The "*z* co-ordinate" measures (and this word, too, ought to be in quotation marks, speaking as we are of an effect of true research that is in principle not measurable) the transformation of the object of science, its methods and its subject. The object of science can be changed in various ways, some of which place in jeopardy our resources of minerals, plant and animal life, pure water or air. But the irreversible process is something different—the creation of a rationally composed system of natural productive forces—what V. I. Vernadsky and Teilhard de Chardin called "the noösphere of the Earth". The transformation of the methods of science is a transformation of the means of experimentation and of the logico-mathematical apparatus, including, for instance, extraterrestrial astronomy, labeled atoms, cybernetics, the mathematization of science... The transformation of the subject of science means associated scientific work, the rational methodology of science, the elevation of knowledge, talent, and that hard-to-define but undoubted prerequisite for creative work that Spinoza called *amor intellectualis*.

I would like to single out this condition, this element of the "*z* axis". It is related to the moral potential of society.

What, then, is the contribution made by scientific errors and their correction to this upward movement along the *z* axis, this irreversible increase in the value of science and of its effect on civilization? The sum of all available and reliable ideas about the universe cannot serve directly as a basis for intellectual and moral resonance. At all events, it does not serve so at present; in the past, the idea of a perfect and final truth did have this resonance—did not the fictitious perfection of Newton's mechanics inspire Pope's lines:

> Nature and Nature's laws lay clothed in night:
> God said "Let Newton be!"—and all was light.

The basic stimulus towards intellectual and emotional uplift, the basis for *amor intellectualis* at the present time, is rather the interrogatory component that is contained within the positive content of science—the pledge and the requirement of changes in our view of the world.

Science and its humanist values are to some extent analogous to the electrical and magnetic fields in Maxwell's electrodynamics: the magnetic field has to undergo a change in order to bring about the appearance of an electric field. But there is also an essential difference here. The magnetic field also generates an electric field when it changes back to its original state: this is the principle of the electromagnetic generator. *Amor intellectualis*, however, is only generated by an irreversible change in scientific ideas. Reversible changes are more likely to generate pessimistic or agnostic impressions, or thought about a "history of errors".

In truth, the *history* of errors and the *history* of truth are inseparable. The evolution of truth is not a passive reaction to new empirical data; the very content of science conceals questions that have never received a certain answer, contradictions, ambiguous hypotheses, and everything that *may* turn out to be a mistake, or *may* be retained and receive a new meaning, or *may* by subjected to limitation or modification.

The successive changes in the logic, the methods and the structure of science constitute scientific revolution. Such revolutions create the irreversible history of science; their results are irreversible; the further revolutionary transformation of science may limit the applicability of the results but it cannot abolish them. Most importantly of all, scientific revolutions lead to an irreversible intellectual and emotional advance. The changing of the logic, the methods and the structure of science is an essential aspect of scientific revolution. It is likely that in the future—perhaps the very near future—the theory of scientific revolutions and the history of science as a whole will include, among the criteria of the revolutionary transformation of science, not only the differences characterizing fundamental ideas, and not only the modification of the "paradigms" of Thomas Kuhn [4], but also the consistency and the irreversibility of such modifi-

[4] T. Kuhn, *The Structure of Scientific Revolutions*, Moscow, 1975.

cations, and therefore the positive and irreversible content of each "paradigm". The basis for this expectation is Lenin's idea of true human knowledge as a tree, on which even sterile flowers may grow, but which nonetheless remains the tree of absolute and objective knowledge[5]. This characteristic of knowledge makes its history irreversible.

[5] See V. I. Lenin, *Complete Works*, vol. 29, Moscow, 1969, p. 321.