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THE STYLE AND CONTENT OF SCIENCE

I. DYNAMIC STYLE

Born and Pauli, in talking of the style of science, meant its relatively stable features, which characterized a long period of scientific progress. "I do not mean," wrote Born in 1953, "that there exist (outside mathematics) any unchanging principles, *a priori* principles in the strict sense of the term. But I think that certain general tendencies of thought exist, which change very slowly and which form definite philosophical periods with their own characteristic ideas in all fields of human activity, including science. In a recent letter to me, Pauli used the expression 'styles'; styles of thought, not only in art but in science too. In adopting this term, I would assert that style is also a characteristic of physical theory, and it is precisely this fact that gives its principles a certain constancy. They are, as it were, *relatively a priori* principles in relation to the particular period. If one is familiar with the style of one's time, one can make certain cautious predictions. One can at least reject ideas that are foreign to the style of one's time".[1]

Let us note that even mathematics has no *absolutely* constant and, in this sense, strictly *a priori* principles, such as might lay claim to physical significance. Euclid's postulate will be a correct or incorrect description of the world depending on whether a

Translated by Nicolas Slater.

[1] M. Born, *Proc. Phys. Soc. 66* n° 402 A (1953).

gravitational field exists in a particular place, and on whether the paths of physical bodies curve in this field or not. In physics itself the "*relatively a priori*" that Born speaks of is not characteristic of the present time: at present every great discovery to some extent rocks the style of science, and introduces into a definition of this style some new nuances. This is the reason for the high degree of dynamism that characterizes our time. Contradictions, research, the advancement of science, have been an integral part of scientific progress. Rousseau, in his *Discourse on the Sciences and the Arts*, speaks of the ancient legend according to which the deity that gave science to mankind was the enemy of human tranquillity. Now, in the second half of the twentieth century, science is constantly advancing new concepts "on credit," while waiting for the appearance of a noncontradictory theory that would give logical harmony to the assortment of procedures of quantum electrodynamics. Anxiety and expectation have now become the noisy accompaniment to a calm and positive melody—the accumulation of unambiguous conceptions of the world. This high degree of anxiety implies a high degree of dynamism, a state of fluidity affecting very general physical, logical and mathematical concepts and principles, scientific and technical ideas and norms, technological processes and constructions and technical-economic indices.

Since the middle of this century instability has itself become a fairly stable feature of scientific progress. In this sense, the high degree of anxiety—the high negative cost of dynamism, Rousseau's divine gift—fits the definition of the style of science and of civilization.

The scientist of classical times, as he searched for ever more fundamental laws, remained certain that he was digging down towards a fixed primordial stratum. Today such a hope (though it now seems less of a hope than a fear) is lost.

In science, and in an analogous way in production too, the high degree of dynamism is accompanied by a new relationship between local, individual, microscopical events, on the one hand, and macroscopic processes on the other. In contemporary physics, we no longer limit ourselves to analysing the dependence of elementary processes in a local region, "here and now," on a general law. The effect of the elementary event upon the general law is becoming ever more important. In quantum mechanics the location of a particle at a given point, its spatial localization, is regarded as an event that modifies the particle's velocity and direction. In the theory of elementary particles there is an even more paradoxical situation: the transmutation of a particle, its transformation into a particle of another type, with a different mass and charge, means replacing one universal line, one set of rules governing its macroscopic behaviour, by another potential universal line. But this is not all. The most recent conceptions of both the evolution of the Meta-galaxy, and the subnuclear world, present the existence of a particle as the result of the interaction of all the particles that make up the universe. This constitutes a rejection of the concept of elementarity.[2] At the same time, local events can give rise to a cosmic chain reaction.

What is the relationship today between local events and the systems that include them in the sphere of production?

One characteristic feature of our contemporary atomic civilization (and also a characteristic feature of the forces leading towards a transition to a *post-atomic civilization*, founded on the direct application of concepts relating to the subnuclear world, the world of elementary particles) is a new relationship between individual acts and general macroscopic processes embracing production as a whole—unique chain reactions that connect local events to their macroscopic results. A typical example would be the effect of production on ecology, the possibility of an abrupt ecological change over a large area caused by the technological processes of a single enterprise, or even individual acts of production. We will shortly return to this peculiarity of contemporary production, technology and civilization as a whole.

II. THE STYLE OF SCIENTIFIC THOUGHT AND "THE PENETRATION OF REASON INTO ITSELF"

The term "style," for all the variety of its possible meanings, always implies something repeatable, some sort of identity of means, methods and processes. But it does not imply repetition of the results of the same events in changed circumstances; it is not a mere statement of regularity and orderliness in life. It

[2] G.F. Chew, S.C. Frantschi, *Phys. Rev.* 7, p. 394, 1961.

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does not even imply that the causal mechanisms leading to particular results are repeatable. The term "style" is not applied to elemental processes. It is applied to art, to literature, to many fields of human activity; but it is not a feature of the laws on which they are based, nor of the results expected or obtained. In architecture, style implies some general quality which distinguishes buildings that vary in their conditions, relief, purpose, scale and aesthetic worth. That is style in architecture. But every period has its own style in art as a whole. This is a general quality that applies to different genres—painting, sculpture, architecture, poetry, etc.—an invariant in the transition from one genre to another—an *intergeneric invariant.* The culture of a particular age is also distinguished by characteristic features in its artistic and scientific creation—a *historico-cultural invariant.* The style of an age is the most general characteristic of human activity and its results, which unites the various fields of creativity, genres and objects, which distinguishes the social psychology, the level of civilization, the interests, tastes and inclinations of the age.

Style is not a characteristic either of isolated objects, or of the classes to which they belong by their nature, structure and functions. Such isolated objects and classes differ according to the field of creation to which they belong, their genre and their purpose. Style is a characteristic of the invariant quality of the relationship between the elements of a class and the classes themselves. Unlike the elements and classes, the relationship (in so far as it is determined by human activity) reflects the active side, the subjective moments of knowledge and transformation of the world. This subjective side of the knowledge of the world depends on the object, on nature, on the elements of being and on their natural surroundings. But it changes with a certain degree of lag, and its relation to the subject of the knowing process confers a relative (and in our days extremely relative!) degree of constancy upon the style of thought and creation. It is this constancy, in Born's view, that serves as the basis for a certain amount of extrapolation and prognostication about scientific development.

Take Gothic style. It characterises, in a general way—in the most general way possible—the architecture of the 13th to 15th centuries. The unchanging, invariant, recurring feature of the dominant architectural ideas of the 13th to 15th centuries is the relation of the elements to the ensemble: they are subordinated to the ensemble, the pointed arches serve to uplift the cathedral as much as possible towards the heavens; and this subordination to the ensemble determines the arrangement of the elements. This is a very *realistic* trend, in a medieval sense: universality, form, and idea strive to become reality. But this trend is not realised in Plato's way—rather in Aristotle's: matter does not dissolve in form, the cathedral does not become the embodiment of universality, a visible mechanical concept—matter testifies to its real existence, independent of form, idea, concept, by forming independent decorations, details, sculptures and ornaments. The gargoyles of Notre Dame are no less an integral feature of this Gothic masterpiece than the upward striving it embodies. It is worth remembering that the mechanical construction that expresses this upward striving was not simply mechanical as far as medieval thought was concerned: both "up" and "down" were not only spatial but religious and moral definitions.

The (mechanically speaking) arbitrary forms, ensembles and ornaments are more independent in the 14th century than the 13th, and even more so in the 15th. It is precisely this relation of the elements to the ensemble that constitutes the peculiarity of Gothic style, distinguishing it from the Romanesque or from Renaissance architecture. The peculiarity is a constant one, as one passes from one cathedral to another, from cathedrals to public buildings, or from one country to another. This relation of the elements to the ensemble, the inclusion of a purely aesthetic decorative spirit, independent of the idea, the ensemble, mechanics and religion, goes beyond the limits of architecture, and characterises the styles of literature and even of science: it was no accident that Verhaeren referred to the medieval relics in Descartes' philosophy as a "Gothic spirit." We shall return to these comparisons in discussing the style of medieval peripatetic science.

If style is a particular historical form of inclusion of an element into a class that embraces it, then the transformation of style is a function of reason. The traditional division between judgement and reason that originated with Kant and Hegel ascribes to judgement the knowledge of the finite, and to reason the knowledge of the infinite. The knowledge of the finite, the study and explanation of processes accessible to the senses and taking place in limited spatio-temporal domains, lead to the infinite. The explanation may lie in the fact of relating a given phenomenon, process or relation between phenomena and processes, to a class ("this stone falls because all stones fall;" "stones fall because all bodies that are heavier than air fall"... etc.). A law that explains observed phenomena and processes is a universal law for a particular domain; it defines the behaviour of the infinite in the general case of a certain number of phenomena and processes; the function that expresses the law is defined in the domain of the infinite. On the other hand, the explanation of a finite process (for instance, the fall of a stone during a particular period of time) refers to an infinite number of infinitely small events, such as (in the above example) the acceleration that takes place at every point on the stone's path and at every instant of time that passes. Thus, the explanation of the finite—a function of judgement—is indivisible from the concept of infinity. Infinity figures here as the Hegelian "true infinity," it is present in every finite link of its chain.

The knowledge of the infinite—a function of reason—consists in the representation of it through the finite, and in the search for such finite images as bring one to create new infinite series, new laws. Reason is here no longer at the service of judgement, but goes beyond its bounds to create new constructions of judgement, new classes of identified elements, classes that are paradoxical from the point of view of the old laws; and new methods and criteria for identifying elements and including them in classes. This is reason *penetrating into itself.*

This expression appears in Laplace's *Analytic Theory of Probabilities* (S.N. Bernstein took Laplace's phrase as an epigraph to his "Experiment in the axiomatic foundation of probability theory"). "Human reason," says Laplace, "finds less difficulty in moving forwards than in penetrating into itself." And indeed, probability theory falls naturally into the framework of constructions of judgement, within which reason "moves forwards;" but the *transition* from dynamic laws to static ones changes the style of scientific thought and the manner of forming classes: phenomena, characteristics and relationships are ordered, identified and included according to their probabilities in a class that embraces them. Even more does reason penetrate into itself, and even more sharply does the style of science change, when science passes on to a new system of measurement, a new structure of metrical space.

III. INFINITY AND MEASUREMENT

Infinity is a metrical notion; furthermore, it is a local one. This, in point of fact, is the beginning of the chain of logical constructions of Riemann's lecture "On the hypotheses on which geometry is based." Riemann speaks of counting as a method of recording quantitative differences between discrete variables, and measurement as a means of making a quantitative comparison between continuous variables. Measurement means the measurement of an infinitely divisible segment by another infinitely divisible segment: it belongs to the domain of reason, remaining within itself, analysing the infinite objects that characterize it and relating them to finite objects—as Galileo himself did in his *Discourses and Mathematical Demonstrations.* Riemann regards infinity as a local property. It is metrical—it characterizes measurement, or—which amounts to the same—the curvature of space at a particular point. Measurement is a local, physical image of infinity—physical because since the general theory of relativity, the curvature of a four-dimensional variable has acquired physical meaning. This image points to the relationship of finite objects with infinitely small and infinitely large ones. This is a matter of the relation between a finite segment and the infinite number of infinitely small elements that compose it, and between a finite object and the infinitely great system that embraces it, which may be limited or unlimited.

Post-classical science has made manifest the gnoseological nature of measurement. It was created as a physical, real embodiment of variable measurement, of the variable curvature of space, of a variable set of axioms, in so far as the general theory of relativity regards a relative deviation from Euclidean geometry as a gravitational field at every point and at every moment in time. Measurement has now acquired even more distinct gnoseological features, and it clearly expresses the changed relationship between an infinite class and finite elements, and to the same extent, the relationship between a class of infinitely small objects and these objects themselves, as its component elements. It expresses the style of the new, post-classical science. This new gnoseological role of measurement, infinitely clearer than before, enables us to evaluate the connection between measurement and the style of science in the past.

IV. GOTHIC THOUGHT

Ancient culture, for all its complexity, contradictoriness, and for all the many planes on which it existed, does have a general stylistic feature that characterizes it. This is the immobility of the integral scheme of the universe, and its isolation from the slow and qualitatively uniform current of empirical observations. This current flowed faster and wider as the frontiers of Greek culture receded (at the time of Alexander the Great, these more or less coincided with the frontiers of the Oecumene), but without any change in methods of production, which remained stagnant. At the same time, it was precisely a change in the methods of production that provided new causal matrices, into which empirical experience could be fitted. These new matrices are on the same plane as the integral causal concept of the world, they give it a high degree of dynamism, they turn logical collisions into physical ones, they demonstrate the everlasting alliance and the everlasting battle between logical schemes and the experience that modifies them. All this existed, but its development was very slow. Hence the unity and the synthetic nature of ancient culture, which had never passed through the crucible of collisions. This culture was canonical, in the literal sense of the word. The aesthetic of perfect canons in architecture and sculpture, the gods of Epicurus, who were so perfect that they took no part in affairs of the world, these gods whom Marx, with his deep understanding of the unity of ancient culture, identified with the plastic gods of Greek art; the logical canons of Aristotle; and perhaps above all the canonical scheme of perfect movements and natural places that was the peripatetic cosmology. This was mankind's childhood, still unshadowed by any contradiction between ideals and ideal schemes on the one hand, and experimental data on the other.

At the middle of the century, the peripatetic skeleton of perfect geocentric orbits and natural places, and the absolute space that was stretched over this skeleton, began to become more complicated under the onslaught of empirical experience, in which relative movements now figured. Terrestrial applied mechanics stood in opposition to the logically worked-out mechanics of the heavens. They attained a certain degree of harmony in statics, though it was not the old undivided harmony, but a relative one in which conflicts were dissolved; the Gothic cathedrals were its incarnation, but in dynamic problems—which were becoming ever more important—a reconciliation between empirical observation and logical schemes, or the inclusion of empirical elements and local observations into logically constructed classes, became extremely complex.

It is a characteristic feature of Gothic science and culture that the conflict between logical constructs and empirical experience was fairly external, and both sides stood in opposition to one another as mutually exclusive forces. The peripatetic canons acquired the form of religious scholasticism, and its proponents occasionally burned those of the opposite persuasion. The nominalists, on the other hand, in denying the reality of universals, did not put forward any new system of universals that would embrace the system of the world as a whole. As early as the 14th century, they knew about uniform velocity and uniform acceleration, but they had not used these concepts to create a new scheme of the universe. The ideological battle took the form of a collision between various interpretations of peripateticism and Platonism; in religion it took the form of heresies. In every case it was a question of new wine in old skins, of a new interpretation of Aristotle or the Fathers of the Church. Medieval realism tended towards a defense of the reality of *static* universals. Nominalism tended to deny the reality of static universals. Once again one thinks of the Gothic cathedrals, whose pointed arches and flying buttresses embody a real universal, while the figures of saints and gargoyles embody the nominalist tendency of medieval thought, but do not link up with the new system of universals.

V. RENAISSANCE AND BAROQUE SCIENCE

The crusades, medieval crafts, the beginnings of manufacturing, sea trade, artillery, water-mills—all these brought to life a new, dynamic causal matrix which made it possible to pass from static universals, as the basis of a synthesis of ideas about the world,

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to dynamic universals; and made it possible to remember that which had lain in the background of ancient thought, and had been pushed right behind the scenes in the Middle Ages, but had now come to occupy the foreground. The crusades, trade with the Levant, and then the great discoveries, differed from the conquests of Alexander the Great and the travels of Greek merchants in that they provoked, in Europe itself—initially in the towns of Italy, but later in the North as well—the development of industry and shipbuilding. The symbol, the incarnation and the source of scientific ideas is now no longer the medieval cathedrals, but the Venetian arsenal (which Galileo describes at the start of his *Discourses and Mathematical Demonstrations*). The Renaissance was a period in which the empirical sources of science underwent an unprecedented expansion; they could no longer fit into the old, static constructs, and needed to be arranged in a new framework. For Renaissance art, the foundations of artistic style are no longer in the subjection to a general plan, which characterized the Gothic, but in the participation of details in the general plan. In Leonardo da Vinci's painting, the dynamic tendency—the desire to show movement, as it were, seized and held at a particular moment, becomes the most important determinant of artistic style. In his *Treatise on Painting* Leonardo himself compares this tendency with the fundamental problem of science (which it became, in classical dynamics). Leonardo's art discloses these roots of seventeenth-century *science* in fifteenth-century *art*. Of course, the word "discloses" is inexact here; at any rate, it is inadequate. Style always, to some extent, conceals the character of the link between the individual and the general, the local "here-and-now" and spatio-temporal diversity. The subsequent development of this link—for instance, the differential calculus—cannot, of course, entirely disclose the secret of the intuitive understanding of the whole in the "here-and-now" that is embraced by painting. It cannot entirely disclose the harmony of Leonardo's Last Supper, with the geometrical symmetry of its figures echoing the architectural details of the background, with the variety of facial expressions, symmetrically passing, at the centre of the picture, into the peaceful expression of Christ; with the variety of the apostles' movements, culminating in his peaceful pose and the thoughtful turn of his head against the light background of the window. Such harmony, such a dynamic universal is not a characteristic of the subject, the genre, or the nature of the elements of the whole, nor yet of the whole itself. We stand before a stylistic peculiarity, which is preserved in all the typical cultural treasures of the Renaissance and which does not vary from genre to genre nor from subject to subject.

Even before this, Dante had created a poetic encyclopaedia of the dynamic world; and later the idea of the homogeneity and infinity of space was to be put forward, initially in a traditional and scholastic form by Nicholas Kuzanski, and then in a humanist form by Giordano Bruno. Finally, in the mid-fifteenth century Copernicus created the heliocentric system, whose fusion with the nature-philosophy of the Renaissance and with the new causal matrix created by applied mechanics marked a radical turning-point towards classical science.

This turn took place within the framework of a new stage of cultural evolution; it concerned Baroque culture, and was linked with a profound change in the foundations of scientific synthesis and the style of scientific thought.

Baroque science is reminiscent of the artistic works of the period: the torrent of heterogeneous, multicoloured impressions of existence overflowed the banks of peripatetic philosophy, but the new schema to unify local observations had not yet crystallized into general principles and laws. Hence arose pluralism, coexistence, conflict, and sometimes an eclectic union of outdated Aristotelian norms and still indeterminate classical criteria. In Baroque buildings, the architectural details do not so much emphasize the general idea (as in Renaissance buildings), nor supplement it (as in Gothic cathedrals), as hide its indeterminate, shifting, transitional character with their piling-on of heterogeneous elements. In a similar way, the intricate arabesques of Galileo's "Dialogue" or the ambiguous kinetic models of Cartesian physics concealed the incompleteness of the new foundations of science.

These foundations were laid by Newton at the end of seventeenth century, but in the period with which we are concerned here, within the limits of Baroque science, a new ideal of scientific explanation of nature had already been formulated. It had not yet become the criterion for an unambiguous and experimentally verified choice of scientific theories; it had not yet become embodied into a consistently realised scheme of synthesis of scientific ideas, a style of science. But it did already exist. It already reigned, though it did not yet govern. The act of its coronation was Galileo's "Dialogue," and the "Discourses" marked its accession to power.

This was an ideal of mathematical explanation of the universe. At the end of the 17th century and throughout the 18th, it was not only an ideal but also, in its tendency, a universal scientific method.

VI. STYLE AND METHOD

An analysis of the *Principia mathematica* and of the post-Newtonian period demands a more exact definition of certain ideas—a distinction between the style and the method of science.

Style and method are characteristics of the way in which scientific thought synthesizes individual observations, and also (an essential part of synthesis) individualizes particular observations in so far as they cannot be reduced to a generality. But style is predominantly a feature pertaining to the subject of knowledge—to a period, a country, a school, or a thinker—while method is a characteristic of the way itself, its starting-point, direction and destination. A fundamental evaluation of a method depends on the anpropriateness of a chosen path to the objective laws, the objective conditions and tasks of knowledge; on the conformity of its results with objective truth. The method therefore varies according to the content of the epistemological problem, the local elements that figure in it and the general scheme, the general quantity that unites it. In general, the more independent a method is of the knowing subject, and the closer it corresponds to the object of knowledge, the more effective it is. The method is a characteristic of knowledge, independently of the subject who knows; it is an invariant element in the passage from one knowing subject to another, a pledge of the general applicability of knowledge.

The style of scientific thought is more a characteristic of the subject who knows; and here the degree of diffusion, the dominant role of such and such peculiarities of knowledge, or the consistency, reproducibility and stability of these peculiarities for a particular medium, period, school, and for the work of a particular thinker, are essential features. All these, in the first

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instance, are characterized by style. Style is that which is characteristic of an age, a school, a thinker; and it is preserved in the transition from one epistemological problem to another—it is an invariant element in this transition.

It is probably unnecessary to stress the conventional nature of this distinction, the degree to which the recurrent peculiarities in the work of a thinker, a school, an age, depend on the field in which the work is done, on the structure and the objective properties of the object of research and on the method that most effectively discovers these properties. But the distinction does reflect the true evolution of scientific thought. The theory of knowledge concentrates on the logical substrate of the history of science. The history of science includes, besides this substrate, those concrete peculiarities that the medium and the thinker's individuality used in coloring his scientific creativity: that concrete historical web whose generalization lies in the picture of consistent, irreversible evolution of the objects, methods and results of knowledge. In the history of science, such a process of evolution is what Engels termed the "main form of movement," the specific object of research. In the history of art, in which the successive steps in the approach to truth do not play the same part that they do in the history of science, the evolution of style serves as a specific object, a "main form of movement."

Using the definition of style formulated above, as the invariant element in the passage from one work to another (individual style), from one school to another, from one genre to another, and from one cultural field to another, one can construct an "Erlangen programme" for the history of culture. As we know, in his famous Erlangen lecture of 1872, Felix Klein constructed groups in which the invariant elements were the distances between points, which conserved their value during the transfer or rotation of coordinate systems (the metric group), the form of a geometrical figure (projective geometry) and so forth. We can define the character of a particular field of culture (painting, for instance) in each period, and at the boundary of any period, by the stylistic invariants of the transition from one work to another. The character of the dominant tendencies in art is defined by intergeneric invariants. The character of culture as a whole is defined by the stylistic invariants of the transition from one cultural field to another.

Returning to 18th-century science and to the relation between style and method, it must be said that here, in contrast to art, the relation is subject to the irreversible process of evolution towards an increasingly reliable idea of the world, the increasing exclusion of the subjective and the increasing emancipation of method from style. For Giordano Bruno, and to a lesser extent for Galileo, method was close to style; style sometimes takes the place of method; the brilliance of the exposition, the temperament, the conviction and the striving for truth that characterise it seem to be arguments in favour of the concept he is propounding. For Newton, and even more so for Lagrange, style is close to method, it attempts not to conceal or replace the method but rather to display it by becoming transparent. Nonetheless the style exists, and for all its transparency it can be defined.

The methods of research of Newton's *Principia Mathematica*, *Universal Arithmetic* and *Optics* are different, but their style remains invariant: the striving towards unambiguous truth both in local, sensory observations; and in the logically derived general laws that govern local events, obliges Newton to connect the two poles by *metric concepts*. The fundamental definition of Newton's style of thought is a metrical view of the world, as a basis for the univocality and ontological validity of his concept of it. The world, for Newton, is the totality of *measurable* objects and processes, and the unity of the world is expressed in the constancy of measurement, the constancy of metric relationships between variable quantities, the invariance of distances in the course of their transfer, the covariance of equations of movement. Newton's style can be defined in such general terms that it turns out to be the style of classical science of the 17th and 18th centuries as a whole.

VII. THE POST-CLASSICAL SYNTHESIS OF SCIENCE

The post-classical synthesis and style of science, and the post-classical concept of the structure of the world, were discussed at the beginning of this article. It remains to add here that in the transition from classical to post-classical science, the style of mathematical thought changes radically. In post-classical science the metric view of the world represents it as a totality of processes interrelated by variable relationships. The search for uniformity, invariance, conservation, parity, and everything that finds expression in the constancy of metric relationships, is accompanied by a perpetual search for infringements of these observations, transitions to different laws of conservation, different covariant relationships, different formulae of measurement. The mathematics of variable relationships represents an adequate apparatus for contemporary science. But this is not enough. There exists a more general definition of the contemporary style of science, that is, those of its features that reflect not only the character of the object of knowledge or the content of epistemological problems, but also the character of the subject who knows, the psychology of the contemporary scientist and the influence of this psychology on the choice of rational methods of knowledge.

In classical times, when the basic task of science was to reduce individual observations to immutable, fundamental principles, that could lay claim to an *a priori* origin, the mathematics of variable quantities and constant metric relationships appeared to guarantee the possibility of this sort of reduction. Kant used to say that a science contained as much scientific material as it had of mathematical. It was a question of a science that had retained a certain amount of *a priori* content, which guaranteed the reliability of the conclusions that were drawn from this content. For Kant, such a content was constituted by the axioms of geometry, including the postulate of parallels—that is, the foundations of Euclidean geometry. It was a fixed, solidified generalization, which gave an absolute value to the fundamental principles, and provided a basis for the *a priori* and subjective character of space as a form of knowledge—a transcendental aesthetic. In our time, one might say that science contains as much scientific material as it has material that goes against the foundations of mathematics. But one could only say this if the offenses against a constant system of measurement did not presuppose its existence. Such is the general theory of relativity. It would be hard to find a better example of the synthesis of infringements of metric correlations and of their conservation, than covariant differentiation, which allows one to conserve a constant system of measurement for events taking place in *space*, at the cost of varying the measurement of space itself. A gravitational field becomes identical with the curvature of space, with the alteration of its geometrical properties, of its measurement. By virtue of this, geometry becomes dependent on physical fields, and loses all claim to an *a priori* character. Paraphrasing Kant, one might now say that *scientific* is a synonym of mathematical, where the mathematical obviously loses its *a priori* character and becomes physical, acquiring ontological validity. Such a criterion is not, of course, applicable to science as a whole, in all its subdivisions. But if one is speaking of the style of scientific thought, then the increasingly frequent (and in future probably practically constant) review of quasi-*a priori* principles is a fundamental peculiarity of the post-classical synthesis of science. The mobility of the fundamental principles of science, and above all its variable measurement, as a basis of the physical view of the world, both coincides in time and is logically linked with the ontological character of the mathematical ideas of the twentieth century and with their physical content. Russell's definition of mathematics as "a science that neither knows what it is talking about, nor whether what it is saying is true" becomes somewhat dated after the general theory of relativity. The application of mathematics, and applied mathematics, have acquired not only a practical but a gnoseological validity, they confirm the objective character of such fundamental mathematical ideas as Euclidean and non-Euclidean measurement. But now that fundamental post-classical science has become a productive force, indeed the most dynamic productive force, guaranteeing non-null higher derivatives in relation to time where economic indices are concerned, (an acceleration of the degree of productivity of work, and in the future even a non-null third derivative in relation to time of these indices), now applied mathematics in its traditional sense (as the industrial application of mathematical knowledge) is becoming a source of changes in fundamental mathematical ideas, in the nucleus of crystallization of individual scientific observations, the source of the unification and synthesis of science. As a whole, contemporary mathematics, under the influence of the problems of its application, increasingly expresses the new synthesis of science. This synthesis might be called systemic or structural, in contrast to the classical synthesis based on what G. Chew (as we know) called the concept of elementarity. Likewise, mathematics must deal with objects whose elements preserve their complexity, with hierarchies of systems and with the matrices, tensors and other objects that express them and that by their nature are not reducible to separate quantities.

VIII. MAXWELL'S DEMON AND THE AIMS OF SCIENCE

Among the structures studied by contemporary science, there is a class of structures of particular importance for the planning of science itself and of its applications. These are the *structures of initial conditions.* Processes that are subject to differential laws (for instance, the movement of a material point) cannot be unambiguously defined without defining the initial conditions. These may consist in a particular macroscopic order of things, in the existence of macroscopic events, in structuredness, irregularity, in the opposite of entropy which is known as *negative entropy.* The processes by which negative entropy increases (at the cost of decreasing negative entropy, i.e. increasing entropy, in other systems—the "destructuring" of these other systems) create the initial conditions that allow one to foresee the processes of transformation of energy. The initial conditions—and their formation—represent the most plastic domain of natural processes, in which man interferes in a purposeful manner in the course of elemental processes, purposefully arranges the forces of nature—which is what work means. Work increases negative entropy in the regions where it is applied; it orders the arrangement of strands of wool, forming a cloth; at the expense of increasing entropy in the surrounding sphere, it creates a temperature differential in the system of boiler/condenser; it replaces the entropic, disordered arrangement of iron atoms in ore by concentrating them in one place in the form of cast iron. The creation, by work, of zones of purposeful negative entropy is precisely what V.I. Vernadsky called the noösphere of the earth. At present the noösphere occupies a rapidly growing part of the lithospere, the hydrosphere and the atmosphere. This idea may be put more generally: noözones of artificial negative entropy are created in nuclei (e.g., the production of plutonium), in radiations (e.g., lasers), in molecules of living matter (radiation genetics). Contemporary man is becoming ever more like Maxwell's demon, who allows fast-

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travelling molecules through an opening but holds slow ones back and thus creates a temperature differential.

What is the aim that defines these structures of negative entropy? Structures of negative entropy *as a whole*—so it is not simply a matter of individual technological processes or individual acts of purposeful arrangement of the forces of nature, but of production as a whole. The question therefore only has meaning in the context of planned production, in which not only the technology but the whole structure of production is subordinate to the aim.

For science, the question of an integral aim is also only meaningful when one is talking of planned science. Every experiment is related to some aim or other, and therefore consists of the purposeful arrangement of the initial conditions of a particular process. In this respect experiment is akin to technology. But the *integral* aim of science does not define these local combinations of physical parameters—impulses, energy, field tensions, composition of chemical compounds, temperature etc.—but the purposeful distribution of social effort among different investigations, different branches, problems, levels, scientific centres... The integral aim defines the structure of work, the structure of funds, the dynamic balance of the distribution of labor resources. Science here figures as a part of the general purposeful activity of mankind. It becomes an economic category. Economic indices enter into science as one of its problems. Together with the immediate problems of an experiment and with the creation of the initial conditions for certain processes between which certain relationships and the laws governing them must be established (this being the point of the experiment), there is a more remote aim, namely an idea of the effect of science and of the effect of the results of the experiment, foreseen with this or that degree of probability, upon technological and economic indices.

The same applies to theoretical investigations as well. They largely consist in mentally picking out a particular objective process, either before or after a real experiment. Science has at its disposal a mathematical apparatus that allows it to single out a particular process from an indivisible reality. In electronic computers this ideal mechanism of taking reality to pieces coincides with a real process, a chain of physical events in electronic valves or semiconductors, which give rise to a spatially and temporally concentrated model of the processes that are being examined and about which predictions are being made.

What is the integral aim of the totality of experiments and theoretical constructs of science? What is the aim of science? Why, for what purpose, has mankind accepted from the hands of a god hostile to his tranquillity this gift that has taken away his rest for ever?

To refer here to purely epistemological aims would be, literally, beside the point: the *point*, the aim, is not an immanent gnoseological criterion of science. Science investigates what is, not what ought to be; in the words of Henri Poincaré, it always uses the indicative mood and never the imperative. From Bacon onwards, science has turned away from teleological idols, and confines itself to prediction without concerning itself with plans. The basic criterion of a plan, an aim, an active interference in nature, is the previous awareness of the result of processes that have been studied, made the subject of predictions and chosen from among the optimal processes about which predictions have been made. It is not one of the truly gnoseological criteria of truth. Truth is not that towards which people aspire—it is that which is.

And yet we aspire towards truth. But not some concrete, already known truth. It is a long time since the ideal of science was some system of nature (for example, Helmholtz's ideal—a system of central forces to explain the whole mechanism of the universe); science ever strives towards the unknown, it seeks to go forward towards a new, unknown but objective truth, whatever it may be. And the task of an experiment is not to reach an already known truth, but to test a probable truth, a possible one, one that is not excluded but that is not certainly true: and to do so no matter what the result of the test.

This sort of dynamic and indeterminate aim is also characteristic of science as a whole. Can it be defined in metric terms?

The analysis of infinitely small quantities allows one to define movement in purely local terms, without the Aristotelian criteria of approach towards a natural place or of a perfect kinetic scheme. The local definition of movement, which was contrasted in the seventeenth century with the peripatetic definition, is velocity and acceleration at a given point. Even non-local criteria have acquired the appearance of an integral of the differential characteristics of movement (the principle of the minimum effect, integral equations as a whole, functionals, and functional analysis). Can analogous differential criteria to those of velocity and acceleration appear when one is speaking of the movement of science and of scientific progress?

Knowledge consists in the search for and the discovery of laws, regular series of phenomena, events, objects, that follow one after another not by chance but uniformly, in accordance with a law, an identity or a symmetry. This does not exclude, but indeed postulates, the individual existence of objects, the infringement of a law, the transition to another law, and so forth. But the discovery of order, *ratio*, negative entropy, identity, has always been and always will be the basic definition of science. Science tears from the unknown a stretch of territory in which it has found some regularity, structure and negative entropy.

Can one, and should one, find a measure for the known negative entropy of the world, a measure for the velocity and acceleration of the zone in which we know the laws that govern existence? It must only be a question of the zone that is truly known, unequivocally and reliably known. But what is reliably known, what has become part of science, what can still be refined but cannot be refuted, what has *become the property of humanity* and not of science alone at a particular moment—this is the totality of practically applied knowledge.

Here we pass from the integral epistemological task of science to its integral applied task. The integral task of production is to increase negative entropy in those systems where the forces of nature are subject to the conscious aims of man. A metric definition is possible here. The metric definition of the volume and rate of scientific progress can be given by a definition of the volume and rate of growth of the integral economic effect of science.

IX. THE INTEGRAL ECONOMIC EFFECT OF SCIENCE AND THE MEASUREMENT OF SCIENTIFIC PROGRESS

Take n disciplines, directions, problems etc. among which funds are distributed. Every distribution, every investment structure, is represented by a point in n-space, where n coordinates represent investment in n branches or problems.

All this is meaningful when investment in science is defined. If investments in science are comparable in size with investment in the fundamental branches of production, and if scientific discoveries can bring about substantial changes in the structure of production, then we have the following situation: the optimal structure of science is that structure whose effect on the dynamics of production brings it close to the economically optimal state.

This idea of an economically optimal dynamics of production can be elucidated by a graph that is analogous to the one just described. Let the number of planned branches of production be represented as N. The volume of each branch is the coordinate of a point in N-space. The transition to other structures is a curve in N-space. If the rate of transition is to be represented, we must use $(N + 1)$-space, where the $(N + 1)$ dimension is time.

We shall attempt to show that the criterion for the choice of an optimal "universal line" of production, an optimal $(N + 1)$-dimensional curve to represent the dynamics of the structure of *production*, is a metric criterion of the optimal structure of *science*. In other words, we shall try to show that the integral aim of science, that determines its structure, coincides with the integral economic effect of science.

The integral aim of science, and the integral aim of production, consist in the humanization of man, his continued movement away from general biological laws, and the increasing importance of specific human laws that define the life of *Homo sapiens*. Work was the beginning of the humanization of the ape, and then it became a factor in the humanization of man. Work, in its historic evolution, increases the sum of natural forces that can be purposefully controlled by man, and at the same time (through the effect of productive forces on the relationships of production) it liberates man from his subjection to elemental social forces and leads to "the leap from the kingdom of necessity to the kingdom of freedom."

The power of the purposefully controlled forces of nature, the power of the noözone that surrounds man and of the artificially created conditions of negative entropy, is measured very accurately by the productivity of the work done by society. But it is not only a static noözone that characterises man; it is also the growth of this zone: and this property also measures the distance that has been covered by man since the dawn of civilization up to the present time. This may be measured by the rate of growth of productivity of work, which at a particular moment becomes continuous and can be expressed by a derivative in relation to time of the level of productivity of work. And, finally, the very rate of growth of the power of the purposefully controlled forces of nature increases with time. If it increases practically continuously, if there is a continuous acceleration, then we arrive at a non-null second derivative in relation to time of the productivity of work. The fundamental economic index is now therefore the expression $\Omega = f(P,P',P'')$, i.e., the function of the productivity of work P, its first derivative in relation to time P' and its second derivative P''.

In the last analysis, these indices give a metric character to the power and the increase of power of the structures of negative entropy created by man. But the power of science and the rate of scientific progress is measured by such a certain and unequivocal knowledge of the structures of negative entropy of the world as is defined by their practical use. Thus the measurement of science is its "econometry"—its metrically defined economic effect. The $(N + 1)$-space of the dynamics of economic structures has as its fundamental index the above-mentioned index Ω, whose maximum serves as the criterion for the optimal "universal line" of the structure, while P' depends on applied science and P'' on fundamental science.