The Representation of Nature in Contemporary Physics*

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The problems of modern art, so frequently and passionately discussed in our time, force us to examine those foundations which form the presupposition for every development of art, foundations which at other times are taken as self-evident. Indeed, the question has been raised whether the relation of modern man toward nature differs so fundamentally from that of former times that this difference alone is responsible for a completely different point of departure for the fine arts in contemporary culture. Certainly the relation of our period toward nature hardly finds its expression, as it did in earlier centuries, in a developed natural philosophy; rather, it is determined mainly by modern science and technology.

For this reason it is worthwhile to consider the view of nature held by modern science, and in particular by contemporary physics. From the start, however, a reservation must be made: there is little ground for believing that the current world view of science has directly influenced the development of modern art or could have done so. Yet we may believe that the changes in the foundations of modern science are an indication of profound transformations in the fundamentals of our existence, which on their part certainly have their effects in all areas of human experience. From this point of view it may be valuable for the artist to consider what changes have occurred during the last decade in the scientific view of nature.

I

First, let us consider the historical roots of recent science. When this science was being established in the seventeenth century by Kepler, Galileo, and Newton, the medieval image was at first still unbroken: man saw in nature God's creation. Nature was thought of as the work of God. It would have seemed senseless to people of

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that time to ask about the material world apart from its dependence on God. The words with which Kepler concluded the last volume of his *Harmony of the World* may be cited as a document of that era:

> I thank thee, O Lord, our Creator, that thou hast permitted me to look at the beauty in thy work of creation; I exult in the works of thy hands. See, I have here completed the work to which I felt called; I have earned interest from the talent that thou hast given me. I have proclaimed the glory of thy works to the people who will read these demonstrations, to the extent that the limitations of my spirit would allow.

In the course of a few decades, however, this relation of man toward nature altered fundamentally. As the scientist immersed himself in the details of natural processes, he recognized that it was in fact possible, following Galileo's example, to separate out individual processes of nature from their environment, describe them mathematically, and thus "explain" them. At the same time, it certainly became clear to him what an endless task was thus presented to the infant science. Newton could no longer see the world as the work of God, comprehensible only as a whole. His position toward nature is most clearly circumscribed by his well-known statement that he felt like a child playing at the seashore, happy whenever he found a smoother pebble or a more beautiful sea shell than usual, while the great ocean of truth lay unexplored before him. This transformation in the attitude of the scientist toward nature may perhaps be better understood when we consider that, to some Christian thought of the period, God in heaven seemed so far removed from earth that it became meaningful to view the earth apart from God. Thus there may even be justification in speaking of a specifically Christian form of godlessness in connection with modern science. This would explain why such a development has not taken place in other cultures. It is certainly no coincidence that precisely in that period, nature becomes the object of representation in the arts independent of religious themes. The same tendency comes to expression in science when nature is considered not only independent of God, but also independent of man, so that there is formed the ideal of an "objective" description or explanation of nature. Nevertheless, it must be emphasized that for Newton the sea shell is significant only because it comes from the great ocean of truth. Observing it is not yet an end in itself; rather, its study receives meaning through its relation to the whole.

In the subsequent era, the method of Newton's mechanics was successfully applied to ever wider realms of nature. This period attempted to separate out details of nature by means of experiments, to observe them objectively, and to understand the laws underlying them. It attempted to formulate interrelations mathematically and thus to arrive at " laws " that hold without qualification throughout the cosmos. By this path it finally succeeded in making the forces of nature serve our purposes through technology. The magnificent development of mechanics in the eighteenth century and of optics, heat theory, and heat technology in the nineteenth century bears witness to the power of this innovation.

In proportion to the success of this kind of science, it spread beyond the realm of daily experience into remote regions of nature that could only be disclosed with the aid of technology, which developed in conjunction with science. Newton's decisive realization was that the laws which govern the fall of a stone also determine the orbit of the moon around the earth and thus are applicable in cosmic dimensions also. In the years that followed, natural science began its victory march on a broad front into those remote regions of nature about which we may obtain information only by the detour of technology—that is, by using more or less complicated apparatus. Astronomy used the improved telescope to master ever more remote cosmic regions. Chemistry attempted to understand processes at the atomic level from the behavior of substances in chemical reactions. Experiments with the induction machine and the Voltaic pile gave the first insight into electrical phenomena that were still hidden from the daily life of that era. Thus the meaning of the word " nature " as an object of scientific research slowly changed; it became a collective concept for all those areas of experience into which man can penetrate through science and technology, whether or not they are given to him " naturally " in direct experience. The term *description* of nature also progressively lost its original significance as a representation intended to convey the most alive and imaginable picture possible of nature; instead, in increasing measure a mathematical description of nature was implied—that is, a collection of data concerning interrelations according to law in nature, precise and brief yet also as comprehensive as possible.

The expansion of the concept of nature that had half unconsciously been completed in this development did not yet have to be considered as a fundamental departure from the original aims of science; the decisive basic concepts were still the same for the expanded area of experience and for the original direct experience of nature. To the nineteenth century, nature appeared as a lawful process in space and time, in whose description it was possible to ignore as far as axioms were concerned, even if not in practice, both man and his interference in nature.

The permanent in the flux of phenomena was taken to be matter unchangeable in mass and capable of being moved by forces. Since chemical phenomena from the eighteenth century on had been successfully organized and interpreted through the atomistic hypothesis taken over from antiquity, it seemed plausible to consider the atoms, in the sense of classical natural philosophy, as the truly real, as the unchangeable building stones of matter. As in the philosophy of Democritus, sensual qualities of matter were taken as appearance; smell and color, temperature and toughness were not intrinsic properties of matter, but originated as interactions between matter and our senses and thus had to be explained through the arrangement and motion of the atoms and the effects of this arrangement on our senses. In this way the all-too-simple world view of nineteenth century materialism was formed: the atoms, as intrinsically unchangeable beings, move in space and time and, through their mutual arrangement and motion, call forth the colorful phenomena of our sense world.

A first inroad into this simple world picture, though one not too dangerous, occurred in the second half of the last century through the development of electrical theory in which not matter but rather the force field had to be taken as the intrinsically real. Interactions between fields of force without a substance as carrier of the forces were less easily understandable than the materialistic conception of reality in atomic physics. An element of abstraction and lack of visualizability was brought into the otherwise apparently so obvious world view. That is why there was no dearth of attempts to return to the simple conception of matter in materialistic philosophy through the detour of a material ether that would carry these fields of force as elastic tensions. Such atttempts, however, never quite managed to succeed. Nevertheless it was possible to be consoled by the fact that changes in fields of force could be considered as occurrences in space and time, describable objectively—that is, without consideration of the means of observation. Thus they corresponded to the generally accepted ideal of a process operating according to law in space and time. It was further possible to think of the force fields, since they can only be observed through their interaction with atoms, as called forth by the atoms, and thus to use them in a certain sense only in explaining the motions of atoms. To that extent, the atoms remained after all the intrinsically real; between them was empty space, which at most possessed a certain kind of reality as carrier of the force fields and of geometry.

For this world view it was not too significant that after the discovery of radioactivity near the end of the last century, the atoms of chemistry could no longer be taken as the final indivisible building blocks of matter but were themselves found to be composed of three types of basic building blocks, which we today call protons, neutrons, and electrons. This realization led in its practical consequences to the transmutation of the elements and to nuclear technology, and thus became tremendously important. As far as fundamental questions are concerned, however, nothing has changed now that we have recognized protons, neutrons, and electrons as the smallest building blocks of matter and interpret these as the intrinsically real. For the materialistic world view, it is important only that the possibility remains of taking these smallest constituents of the atoms as the final objective reality. On this foundation rested the coherent world view of the nineteenth and early twentieth centuries. Because of its simplicity it preserved for several decades its full powers of persuasion.

Precisely at this point profound changes in the foundations of atomic physics occurred in our century which lead away from the reality concept of classical atomism. It has turned out that the hoped-for objective reality of the elementary particles represents too rough a simplification of the true state of affairs and must yield to much more abstract conceptions. When we wish to picture to ourselves the nature of the existence of the elementary particles, we may no longer ignore the physical processes by which we obtain information about them. When we are observing objects of our daily experience, the physical process transmitting the observation of course plays only a secondary role. However, for the smallest building blocks of matter every process of observation causes a major disturbance; it turns out that we can no longer talk of the behavior of the particle apart from the process of observation. In consequence, we are finally led to believe that the laws of nature which we formulate mathematically in quantum theory deal no longer with the particles themselves but with our knowledge of the elementary particles. The question whether these particles exist in space and time "in themselves" can thus no longer be posed in this form. We can only talk about the processes that occur when, through the interaction of the particle with some other physical system such as a measuring instrument, the behavior of the particle is to be disclosed. The conception of the objective reality of the elementary particles has thus evaporated in a curious way, not into the fog of some new, obscure, or not yet understood reality concept, but into the transparent clarity of a mathematics that represents no longer the behavior of the elementary particles but rather our knowledge of this behavior. The atomic physicist has had to come to terms with the fact that his science is only a link in the endless chain of discussions of man with nature, but that it cannot simply talk of nature "as such." Natural science always presupposes man, and we must become aware of the fact that, as Bohr has expressed it, we are not only spectators but also always participants on the stage of life.

II

Before we can speak of the general implications arising out of this new situation in modern physics, it is necessary to discuss a development which is more important for practical purposes, namely the expansion of technology which has proceeded hand in hand with the growth of science. This technology has carried natural science from its origin in the West over the face of the earth and helped it to a central position in the thought of our time. In this process of development during the last two hundred years technology has always been both presupposition and consequence of natural science. It is presupposition because an extension and deepening of science often can take place only through a refinement of the means of observation. The invention of the telescope and microscope and the discovery of X-rays are examples. Technology, on the other hand, is also a consequence of science, since the technical exploitation of the forces of nature is in general only possible on the basis of a thorough knowledge of the natural laws of that particular realm of science.

Thus in the eighteenth and early nineteenth centuries there first developed a technology based on the utilization of mechanical processes. The machine at that stage often only imitated the actions of man's hand, whether in spinning and weaving or in the lifting of loads or the forging of large pieces of iron. Hence this form of technology was initially seen as an extension of the old crafts. It was understandable and obvious to the onlooker in the same way as the work of the craftsman, whose fundamental principles everyone knew even if the detailed techniques could not be copied by all. Even the introduction of the steam engine did not fundamentally change this character of technology; however, from this time on the expansion of technology could progress at a formerly unknown rate, for it now became possible to place the natural forces stored in coal in the service of man to perform his manual work for him.

A decisive transformation in the character of technology probably began with the technical utilization of electricity in the second half of the last century. It was hardly possible to speak any longer of a direct connection with the earlier crafts. Natural forces were now exploited that were almost unknown to people in direct experience of nature. For many people, even today, electricity has something uncanny about it; at the least it is often considered incomprehensible, though it is all around us. The high-voltage lines which one must not approach admittedly give us a kind of conceptual lesson concerning the force field employed by science, but basically this realm of nature remains foreign to us. Viewing the interior of a complicated electrical apparatus is sometimes unpleasant in the same way as watching a surgical operation.

Chemical technology also might be seen as a continuation of old crafts such as dyeing, tanning, and pharmacy. But here also the extent of the newly developed chemical technology from about the turn of the century no longer permits comparison with the earlier circumstances. Nuclear technology, finally, is concerned with the exploitation of natural forces to which every approach from the world of natural experience is lacking. Perhaps this technology, too, in the end will become as familiar to modern man as electricity, without which man can no longer conceive his environment. But the things that are daily around us do not for that reason become a part of nature in the original sense of the word. Perhaps, in the future, the many pieces of technical apparatus will as inescapably belong to man as the snail's house to the snail or the web to the spider. Even then, however, these machines would be more parts of our human organism than parts of surrounding nature.

Technology thus fundamentally interferes with the relation of nature to man, in that it transforms his environment in large measure and thereby incessantly and inescapably holds the scientific aspect of the world before his eyes. The claim of science to be capable of reaching out into the whole cosmos with a method that always separates and clarifies individual phenomena, and thus goes forward from relationship to relationship, is mirrored in technology which step by step penetrates new realms, transforms our environment before our eyes, and impresses our image upon it. In the same sense in which every detailed question in science is subordinate to the major task of understanding nature as a whole, so also does the smallest technical advance serve the general goal, that of enlarging the material power of man. The value of this goal is as little questioned as the value of natural knowledge in science, and the two aims coalesce in the banal slogan "Knowledge is Power." Probably it is possible to demonstrate in the case of every technical process its subservience to this common goal; it is, on the other hand, characteristic for the whole development that the individual technical process is bound to the common goal in such an indirect way that one can hardly view it as part of a conscious plan for the accomplishment of this goal. Technology almost ceases to appear at such times as the product of conscious human effort for the spreading of material power. Instead it appears as a biological process on a large scale, in which the structures that are part of the human organism are transferred in ever larger measure to man's environment. Such a biological process would be outside man's control, for man can indeed do what he wills, but he cannot will what he wills.

III

It has often been said that the profound changes in our environment and our way of life in the technical age have also transformed our thinking in a dangerous way. Here, we are told, is the root of the crises by which our era is shaken—and by which modern art is shaped. But this objection is older than the technology and science of our time; technology and machines in a more primitive form have existed in much earlier times, so that men were forced to think about such questions in periods long past. Two and a half thousand years ago, the Chinese sage Chang Tsi spoke of the dangers to man of using machines. I would like to quote a section from his writings that is important for our subject:

> When Tsi Gung came into the region north of the river Han, he saw an old man busy in his vegetable garden. He had dug ditches for watering.

He himself climbed into the well, brought up a container full of water in his arms, and emptied it. He exerted himself to the utmost, but achieved very little.

Tsi Gung spoke: "There is an arrangement with which it is possible to fill a hundred ditches with water every day. With little effort much is accomplished. Wouldn't you like to use it?" The gardener rose up, looked at him and said, "What would that be?"

Tsi Gung said, "A lever is used, weighted at one end and light at the other. In this way water can be drawn, so that it gushes out. It is known as a draw-well."

At that, anger rose up in the face of the old man and he laughed, saying, "I have heard my teacher say: 'When a man uses a machine he carries on all his business in a machine-like manner. Whoever does his business in the manner of a machine develops a machine heart. Whoever has a machine heart in his breast loses his simplicity. Whoever loses his simplicity becomes uncertain in the impulses of his spirit. Uncertainty in the impulses of the spirit is something that is incompatible with truth.' Not that I am unfamiliar with such devices; I am ashamed to use them."

That this ancient tale contains a considerable amount of truth, everyone of us will agree; "uncertainty in the impulses of the spirit" is perhaps one of the most telling descriptions we can give to the condition of man in the present crisis. Nevertheless, although technology, the machine, has spread over the world to an extent that the Chinese sage could not have imagined, two thousand years later the world's finest works of art are still being created and the simplicity of the soul of which the philosopher spoke has never been completely lost. Instead, in the course of the centuries it has shown itself, sometimes weakly, sometimes powerfully, and it has borne fruit again and again. Finally, the ascent of man has, after all, occurred through the development of tools; thus technology cannot carry the whole blame for the fact that the consciousness of this interconnection has in many places been lost.

Perhaps we will come nearer the truth if the sudden and—measured by earlier changes—unusually swift diffusion of technology in the last fifty years is held responsible for the many difficulties. The speed of technological transformation, in contrast to that of earlier centuries, leaves no time to mankind in which to adjust to the new conditions of life. But even this is probably not the correct or the complete explanation of why our time seems to face a new situation, hardly without analogy in history.

We have already mentioned that the changes in the foundations of modern science may perhaps be viewed as symptoms of shifts in the fundamentals of our existence which then express themselves simultaneously in many places, be it in changes in our way of life or our usual thought forms, be it in external catastrophes, wars, or revolutions. When one attempts to grope one's way from the situation in modern science to the fundamentals that have begun to shift, one has the impression that it is not too crude a simplification of the state of affairs to assert that for the first time in the course of history man on earth faces only himself, that he finds no longer any other partner or foe. This observation applies first of all in a commonplace way in the battle of man against outward dangers. In earlier times he was endangered by wild animals, disease, hunger, cold, and other forces of nature, and in this strife every extension of technology represented a strengthening of his position and therefore progress. In our time, when the earth is becoming ever more densely settled, the narrowing of the possibilities of life and thus the threat to man's existence originates above all from other people, who also assert their claim to the goods of the earth. In such a confrontation, the extension of technology need no longer be an indication of progress.

The statement that in our time man confronts only himself is valid in the age of technology in a still wider sense. In earlier epochs man saw himself opposite nature. Nature, in which dwelt all sorts of living beings, was a realm existing according to its own laws, and into it man somehow had to fit himself. We, on the other hand, live in a world so completely transformed by man that, whether we are using the machines of our daily life, taking food prepared by machines, or striding through landscapes transformed by man, we invariably encounter structures created by man, so that in a sense we always meet only ourselves. Certainly there are parts of the earth where this process is nowhere near completion, but sooner or later the dominion of man in this respect will be complete.

This new situation becomes most obvious to us in science, in which it turns out, as I have described earlier, that we can no longer view "in themselves" the building blocks of matter which were originally thought of as the last objective reality; that they refuse to be fixed in any way in space and time; and that basically we can only make our knowledge of these particles the object of science. The aim of research is thus no longer knowledge of the atoms and their motion "in themselves," separated from our experimental questioning; rather, right from the beginning, we stand in the center of the confrontation between nature and man, of which science, of course, is only a part. The familiar classification of the world into subject and object, inner and outer world, body and soul, somehow no longer quite applies, and indeed leads to difficulties. In science, also, the object of research is no longer nature in itself but rather nature exposed to man's questioning, and to this extent man here also meets himself.

Our time has clearly been given the task of coming to terms with this new situation in all aspects of life, and only when this is accomplished will man be able to regain that " certainty in the impulses of the spirit " talked of by the Chinese sage. The way to this goal will be long and arduous, and we do not know what stations of the cross are still ahead. But if indications are sought as to the nature of the way, it may be permissible to consider once more the example of the exact sciences.

In quantum theory, we accepted the described situation when it became possible to represent it mathematically and when, therefore, in every case we could say clearly and without danger of logical contradiction how the result of an experiment would turn out. We thus resigned ourselves to the new situation the moment the ambiguities were removed. The mathematical formulas indeed no longer portray nature, but rather our knowledge of nature. Thus we have renounced a form of natural description that was familiar for centuries and still was taken as the obvious goal of all exact science even a few decades ago. It could also be said for the present that we have accepted the situation in the realm of modern atomic physics only because our experience can in fact be correctly represented in that area. As soon as we look at the philosophical interpretations of quantum theory, we find that opinions still differ widely; the view is occasionally heard that this new form of natural description is not yet satisfying since it does not correspond to the earlier ideal of scientific truth, and hence is to be taken only as another symptom of the crisis of our time, and in any case is not the final formulation.

It will be useful to discuss in this connection the concept of scientific truth in somewhat more general terms and to ask for criteria as to when an item of scientific knowledge can be called consistent and final. For the moment, a more external criterion: As long as any realm of the intellectual life is developing steadily and without inner break, specific detailed questions are presented to the individual working in this area, questions that are in a sense problems of technique, whose solution is certainly not an end in itself but appears valuable in the interest of the larger relationship that alone is important. These detailed problems are presented to us, they do not have to be sought, and working on them is the presupposition for collaborating at the larger relationship. In the same sense, medieval stone masons endeavored to copy as accurately as possible the folds of garments, and the solution of their special problem was necessary because the folds of the garments of the saints were part of the large religious relationship that was the real aim. In a similar way, special problems have always presented themselves in modern science, and work on these is the presupposition for the understanding of the large relationship. These questions presented themselves, also, in the development of the last fifty years; they did not have to be sought. And the aim was always the same: the large interrelatedness of the laws of nature. In this sense, purely from the outside, there seems to be no basis for any break in the continuity of exact science.

With respect to the finality of the results, however, we should remember that in the realm of exact science final solutions are continually being found for certain delimited areas of experience. The problems, for instance, which could be studied with the concepts of Newtonian mechanics found their final answer for all time through Newton's laws and the mathematical deductions drawn from them. These solutions, to be sure, do not extend beyond the concepts and questions of Newtonian mechanics. Thus electrical theory, for instance, was not accessible to analysis by these concepts. New systems of concepts emerged in the exploration of this new realm of experience with whose help the laws of electricity could be mathematically formulated in their final form. The word "final" in connection with exact science evidently means that we will always find closed, mathematically describable systems of concepts and laws that fit certain areas of experience, are valid in them anywhere in the universe, and are incapable of modification or improvement. It cannot, however, be expected that these concepts and laws will later be suitable for the representation of new realms of experience. Only in this limited sense, therefore, can the concepts and laws of quantum theory be designated as final, and only in this limited sense can it ever happen that scientific knowledge finds its final fixation in mathematical or any other language.

Similarly, certain philosophies of justice assume that justice always exists but that, in general, in every new legal case justice must be found anew, that at all events the written law always covers only limited areas of life and therefore cannot be everywhere binding. Exact science also goes forward in the belief that it will be possible in every new realm of experience to understand nature, but what the word " understand " might signify is not at all predetermined. The natural knowledge of earlier epochs, fixed in mathematical formulas, might be " final," but not in any sense always applicable. This state of affairs makes it impossible to base articles of belief that are to be binding for one's bearing in life on scientific knowledge alone. The establishment of such articles of faith could only be based on such " fixed " scientific knowledge, a knowledge only applicable to limited realms of experience. The assertion often found at the beginning of creeds originating in our time that they deal not with belief but with scientifically based knowledge, thus contains an inner contradiction and rests on a self-deception.

Nevertheless, this realization must not mislead us into underestimating the firmness of the ground on which the edifice of exact science has been built. The concept of scientific truth basic to natural science can bear many kinds of natural understanding. Not only the science of past centuries but also modern atomic physics is based on it. Hence it follows that one can come to terms with a knowledge situation in which an objectification of the process of nature is no longer possible, and that one should be able to find our relation to nature within it.

When we speak of a picture of nature provided by contemporary exact science, we do not actually mean any longer a picture of nature, but rather a picture of our relation to nature. The old compartmentalization of the world into an objective process in space and time, on the one hand, and the soul in which this process is mirrored, on the other—that is, the Cartesian differentiation of *res cogitans* and *res extensa*—is no longer suitable as the starting point for the understanding of modern science. In the field of view of this science there appears above all the network of relations between man and nature, of the connections through which we as physical beings are dependent parts of nature and at the same time, as human beings, make them the object of our thought and actions. Science no longer is in the position of observer of nature, but rather recognizes itself as part of the interplay between man and nature. The scientific method of separating, explaining, and arranging becomes conscious of its limits, set by the fact that the employment of this procedure changes and transforms its object; the procedure can no longer keep its distance from the object. The world view of natural science thus ceases to be a view of " natural " science in its proper sense.

The clarification of these paradoxes in a narrow segment of science has certainly not achieved much for the general situation of our time, in which, to repeat a simplification used earlier, we suddenly and above all confront ourselves. The hope that the extension of man's material and spiritual power always represents progress thus finds a limit, even though it may not yet be clearly visible. The dangers are the greater, the more violently the wave of optimism engendered by the belief in progress surges against this limit. Perhaps the nature of the danger here discussed can be made clearer by another metaphor. With the seemingly unlimited expansion of his material might, man finds himself in the position of a captain whose ship has been so securely built of iron and steel that the needle of his compass no longer points to the north, but only toward the ship's mass of iron. With such a ship no destination can be reached; it will move aimlessly and be subject in addition to winds and ocean currents. But let us remember the state of affairs of modern physics: the danger only exists so long as the captain is unaware that his compass does not respond to the earth's magnetic forces. The moment the situation is recognized, the danger can be considered as half removed. For the captain who does not want to travel in circles but desires to reach a known—or unknown—destination will find ways and means for determining the orientation of his ship. He may start using modern types of compasses that are not affected by the iron of the ship, or he may navigate, as in former times, by the stars. Of course we cannot decree the visibility or lack of visibility of the stars, and in our time perhaps they are only rarely visible. In any event, awareness that the hopes engendered by the belief in progress will meet a limit implies the wish not to travel in circles but to reach a goal. To the extent that we reach clarity about this limit, the limit itself may furnish the first firm hold by which we can orient ourselves anew.

Perhaps from this comparison with modern science we may draw hope that we may here be dealing with a limit for certain forms of expansion of human activity, not, however, with a limit to human activity as such. The space in which man as spiritual being is developing has more dimensions than the one within which he has moved forward in the preceding centuries. It follows that in the course of long stretches of time the conscious acceptance of this limit will perhaps lead to a certain stabilization in which the thoughts of men will again arrange themselves around a common center. Such a development may perhaps also supply a new foundation for the development of art; but to speak about that does not behoove the scientist.