NOTES AND DISCUSSION

Milič Čapek

THE SECOND SCIENTIFIC REVOLUTION

It is easy to guess from the title of this article that its content will deal with the current changes in the foundations of physical sciences—the changes which are far-reaching enough to be called revolutionary. But the full significance of this intellectual upheaval will become clear only if we compare it to *another* scientific revolution which took place in the sixteenth and seventeenth centuries. The significance of this first scientific revolution is fully recognized by the historians of science and historians in general; if I shall recall its main features, it will be only to provide us with a *contrasting backdrop* against which the salient features of the contemporary transformation of physics will stand out more vividly and more suggestively. The comparison between what is going on now and what went on three centuries ago will clearly show that the distance along which physical science moved in the last fifty years is not only greater than that covered in the last three centuries, but also—and this is far more significant—greater than the distance separating the science of Newton from that of Aristotle. In other words, the twentieth century revolution is far more profound than what was rather inappropriately called "the Copernican revolution;" the intellectual distance between

https://doi.org/10.1177/039219216801606306 Published online by Cambridge University Press

Aristotle and Newton is *far smaller* than the distance separating the world of Newton and Laplace from that of Einstein, Planck, de Broglie, and Heisenberg.

This may appear as a hasty and paradoxical statement for various reasons. In the first place, we still teach Newtonian physics on a high school level and in the elementary college courses; and for the reasons which will be mentioned we shall continue to teach it. This seems to indicate that the break between Newtonian and modern physics is perhaps not as sharp as I claimed, and seemingly not as sharp as between Aristotelian physics and the physics of Newton. This objection is also seemingly supported by the fact that Newtonian physics was born painfully and laboriously because it faced the sharp opposition of the previous solidly entrenched medieval view. There is hardly any need to recall how Copernicus' book was placed on the index of prohibited books, how Giordano Bruno died, how Galileo was forced to recant, how extremely cautious Descartes had to be. In contrast to this, modern physics was born in the state-supported institutions, endowed by generous grants, hailed by a large public, appreciated by the military circles, respected even by the churches. The transition from the Newtonian to the Einsteinian physics went on in this respect smoothly and without external interference, at least if we disregard Nazi Germany whose opposition to the relativity theory, however, was more an opposition to its author rather than to its content. Closest to the medieval oppression came the policy of Stalin's Russia where the materialistic scholastics, even today well entrenched in the university circles, regarded the collapse of classical physics as a serious threat to its main dogmas. But if we consider the normally functioning free society—and it was in such society that modern physics was born—there was clearly no interference remotely comparable to that which tried to stifle the incipient classical science more than three centuries ago.

I am perfectly aware of all these objections. But they prove really only two things: *a*) that *the external obstacles* which interfered with the development of the Newtonian science, are absent today, at least in the free part of the world; *b*) that what was so revolutionary in the first scientific revolution was less its ideas than their *implications*. Let me explain these two points in detail. It is understandable that the cultural climate in the twentieth century is different from that in the sixteenth or seventeenth century. Although there is no guarantee that free inquiry will not be again restricted—we have seen this in the Germany of Hitler, in the Spain of Franco, and still in Eastern Europe and China today—it still remains one of the basic presuppositions of experimental and theoretical research which even totalitarian regimes eventually are forced to respect, at least in a limited degree. In this respect, it is almost ironical that the idea of freedom for which Bruno and Galileo were persecuted enables the contemporary scientists to question the very same ideas for which these two men suffered; today we are much less sure of the infinity of space than Bruno was, and we are certain that Galileo's dynamics is only approximately valid. But the fact that the circumstances under which contemporary physics was born were much less dramatic than those in which the astronomy of Kepler and the physics of Newton has nothing to do with the ultimate revolutionary impact of the present transformation of physical sciences. This leads me to the second point. I said that the implications of the first scientific revolution were more revolutionary than the ideas themselves which constituted it. It is true that these implications were fairly obvious and that they can hardly be separated from the ideas themselves; this is the reason why their dangerous character—dangerous to the medieval world view—was soon noticed. But what do we know about the implications of modern physics? And—let us ask more bluntly—how much do we care about them? The technological applications of the present revolution in science are so spectacular that they tend to obscure its theoretical significance. There are other additional factors which tend to obscure it. In the first place, there is a deep crisis in contemporary philosophy which can be compared to the crisis of Greek philosophy at the time of Socrates. We know that both Socrates and the sophists simply turned their back to nature, that is, to the cosmological speculations which so fascinated their Ionic predecessors. When Socrates, during his trial, was accused by Meletus that he regarded the sun and the moon not as divine beings, but as pieces of stone, he answered that these ideas were not his own but those of Anaxagoras. He did not say that Anaxagoras was right; nor did

https://doi.org/10.1177/039219216801606306 Published online by Cambridge University Press

he say that he was wrong; he was simply not interested in this question at all. And immediately before his death, according to the dialogue *Phaedo*, he again emphasized that he had no interest whatever in the problems of physical nature. Although I would hesitate to compare modern existentialists and phenomenologists to Socrates, there is no question that they share with him his complete lack of interest in the problems of science and that their interest is narrowly confined to the problem of man, of human knowledge, and of human values. I would be less hesitant to compare contemporary linguistic analysts to the Greek sophists; perhaps they would even be proud of this comparison. If we remember the circumstances in which the sophistic movement originated, it is difficult not to see the analogy: the same general intellectual fatigue and frustration generated by the discouraging diversity of philosophical systems; the same increase in virtuosity of philosophical argumentation, the same creation of artificial problems, the same blossoming verbosity and hair-splitting trivialities. We know the harsh pronouncement of Bertrand Russell who wrote in *The British Journal for the Philosophy of Science* in the early fifties that the excessive interest in language, which is so characteristic of the present philosophical scene in England and in the English-speaking countries in general, is merely an easy excuse for not being interested in the problems of contemporary science.[1] Perhaps we may find Russell's judgment too harsh; there is hardly any question about the usefulness of the linguistic analysis as long as it is applied to the language of science; but I fail to see any particular relevance in the analysis of ordinary language whose shortcomings and inadequacies have been pointed out long ago by pragmatists and even earlier; and I would especially distrust the common usage which is so obviously conditioned by the social media and the whole macroscopic environment to be a reliable tool in philosophy and, in particular, in philosophy of nature.

Thus the only philosophy which is genuinely concerned about the second scientific revolution is *logical positivism*; ironically enough, it is too much burdened by its intellectual nineteenth-century heritage to be well prepared for this task. In the first

[1] "The Cult of 'Common Usage,'" *British Journal for the Philosophy of Science*, (III) 1952-3, pp. 303-7.

place, the agnostic and anti-metaphysical tradition of the early positivism of August Comte and Herbert Spencer is still present under different terminological garbs in contemporary positivism; at least their antimetaphysical effusions are as eloquent as those of Auguste Comte, even when hardly anybody among them dares to mention his name in order not to look old-fashioned. This anti-metaphysical or, if you prefer, antiontological orientation leads contemporary positivists to ignore or at least to de-emphasize the fact that the present crisis in physics is in the first place the crisis of the *classical picture* of reality, far more radical than the crisis of the Aristotelian picture of the world. Moreover, the positivists today, like the positivists of the last century, are consciously or semi-consciously committed to the mechanistic view of reality; their agnosticism and phenomenalism is largely *verbal* since it merely hides their definite mechanistic commitment. (We shall return to this point in due time.) All these factors led the Vienna circle and its prolific Anglo-American progeny to concentrate on the questions of methodology almost exclusively; hence, philosophy of science is equated by them with methodology; and, since there is a perfect continuity between the methodology of classical science and that of modern physics, the revolutionary character of the latter again is naturally overlooked or at least played down.

A few additional factors should be mentioned. First, to measure the distance between classical and modern physics *a certain degree of historical awareness* is necessary. And this is largely lacking, at least in the United States. As the physicist Dyson wrote some years ago: for those physicists who have grown up after 1940 and have accepted quantum mechanics as a *fait accompli*, it is extremely difficult to imagine the state of mind of the men who were creating the theory before 1926.[2] And let us not forget that in 1926 the second scientific revolution was already a quarter of a century old. On the other hand, an excessive historical awareness may seriously interfere with the understanding of new and fresh ideas. An extensive acquaintance with the ideas of the past may have an enslaving influence on human minds. We have two striking illustrations of it in the persons

[2] F.J. Dyson, in *Scientific American*, vol. 120 (March 1954), p. 92.

of Léon Brunschvicg and Ernst Cassirer, both with impressive knowledge of the history of ideas and a deep understanding of their logical as well as genetic relations. Yet, this knowledge was for them a handicap rather than an advantage when they were dealing with the twentieth-century revolution in science. This handicap showed itself in a lesser degree in Cassirer than in Brunschvicg,[3] it is not entirely absent even in the interpretations of Emile Meyerson,[4] whose writings still remain among the most wonderful specimens of historical scholarship joined to scientific and philosophical erudition. Yet, a certain degree of historical perspective *is* inevitable for any attempt at interpreting the current changes in physics; otherwise, we can easily slip into intellectual traps by commiting fallacies analogous to the fallacies of the past which we could have avoided by having a more solid historical knowledge. It is true that it is very difficult to acquire a proper historical perspective which would free us from what Whitehead called "provincialism in time" and at the same time not to be submerged by sheer weight of historical scholarship. To escape the curse of specialization and the irresponsibilities of dilettantism—to steer our intellectual course between these two dangers—is one of the most challenging tasks of a philosopher of science.

In what, then, does the revolutionary character of the contemporary scientific revolution consist? We pointed out that there were no external obstacles and oppositions comparable to those which the first scientific revolution faced. But the absence of external obstacles does not mean that there are no obstacles at all. As I am going to show, the obstacles and resistances which a modern philosopher of science faces are of more subtle and more elusive, but also of a more insidious kind; they seem to be due to the factors inherent in *the very nature* of human understanding or, more accurately, the *present historical form* of human understanding. A brief comparison with the first scientific revolution will show it quite clearly. What was the meaning of

[3] Cf. on this point the article of Louis de Broglie, "Léon Brunschvicg et l'évolution des sciences," in *Revue de métaphysique et de morale*, vol. 50 (1945), pp. 72-6.

[4] This was pointed out by Gaston Bachelard, *Le nouvel esprit scientifique* (P.U.F., 1946), pp. 131-3; 175-6.

that revolution associated with the names of Galileo and Newton? The earth exchanged its place with the sun, and the last celestial sphere—the sphere of the fixed stars—which was still retained by Copernicus, Tycho Brahe, and Kepler, was swept away by Giordano Bruno; thus the sun became a star and the allegedly fixed stars became very distant suns floating freely in the limitless space. The intellectual effort involved in this imaginative transition "from the closed world to the infinite universe"—to use Professor Koyré's phrase—was relatively small. The difficulties involved in this step were mainly due to the emotional resistance to give up the medieval geocentric scheme, especially since this resistance was embodied in the institution of the medieval Church and of Aristotelian science.

But *intellectually* this step was not hard to achieve; in truth, it was fully anticipated by Greek science. We must not forget that Greek atomists esplicitly insisted on the infinity of space, on the plurality of the worlds, and on the unity of nature in space in contrast to the Aristotelian dualism of the terrestrial and celestial realm which dominated the Western world for nineteen centuries. This explains why the protagonists of seventeenth-century science had merely to repeat the argument of the ancient atomists against the impossibility of finite space: "If I were on the alleged edge of the world and shot an arrow outwards, where would an arrow fly?"—asked Giordano Bruno, and one century after him, John Locke, repeating thus the question which Lucretius asked so many centuries before them. Even Copernicus had his Greek predecessors: not speaking of Philolaus who dislodged the earth from the center of the universe, there was Heraclides of Pontus who taught the rotation of the earth around its axis and Aristarchus of Samos who asserted that the earth besides rotating around its axis also revolves once in a year around the sun. This only shows how unfortunate the influence of the established scientific or philosophical authority—in this case of Aristotle—can be. This also explains why Gassendi was so earnestly reviving the ancient atomism; why Francis Bacon wrote a Latin work in which he tried to rehabilitate Democritus; why in the middle of the seventeenth century Johannes Christopher Magnenus wrote a book with a characteristic title *Democritus reviviscens*—"Democritus revived;" this explains why Newton in the concluding part of his *Optics* wrote that "God in the beginning created matter in solid, hard, impenetrable, moveable particles of such sizes and figures and with such other properties, and in such proportions in space as most conduced to the end for which he formed them...," adding a few lines later the characteristically Lucretian argument that "should they (i.e., atoms) wear away, or break in pieces, the nature of things depending on them would be changed..." It was this passage of Newton which John Dalton, one of the founders of modern chemistry, quoted, showing again the persistence of the atomistic inspiration through the whole history of Western thought. About the fundamental identity of the *corpuscular-kinetic model of nature* from Democritus to Lorentz no doubt is possible; neither can we doubt its historical continuity. It is true that under the pressure of the institutionalized Aristotelianism the atomistic tradition was suppressed and nearly forgotten in the Middle Ages; but, as Kurt Laswitz showed convincingly, it has never been entirely suppressed or forgotten, and survived in a sort of intellectual underground until its triumphant revival in the first scientific revolution.

Why was it so? Was it accidental that so many important ideas of the corpuscular-kinetic scheme were anticipated by the early thinkers? Is there any natural tendency within the human mind to prefer the Euclidian space to any other types of space or to regard solidity as the primary constituting property of matter? Why did the human mind almost spontaneously return to the rejected ideas of atomists as soon as it was free from the pressure of external authority and from the inner pressure of religious prejudices? This is the question which we are facing now and on the way we shall answer it, our attitude to, and understanding of, the second scientific revolution will depend.

Despite the profound differences between the Aristotelian and Newtonian world views, they both had one fundamental feature in common: they were built *of the elements borrowed from our sensory perception*, and thus it was easy to *imagine* them, i.e. to construct in our mind their mental picture. The helio-centric system of Copernicus was perhaps less familiar, but in principle as easily imaginable as the geocentric medieval view; both views were characterized by the preponderance of *visual* elements;

Copernicus' circles and Kepler's ellipses were as visualizable as Ptolemy's epicycles and Aristotle's spheres, having furthermore an advantage of lesser complexity and greater aesthetical appeal. Both views accepted Euclidian space; but while Aristotle failed to see that the geometry of Euclid implied the infinity of space Bruno and Newton saw this consequence clearly. Another significant difference was that while the Aristotelian physics still objectified the secondary qualities, the physics of Galileo and Newton *excluded* them from nature and retained only the basic geometrical and mechanical attributes of matter like position, size, shape, motion and mass. In other words, the *only* building material which was used in constructing the classical picture of the world was derived from the sensations of *sight* and *touch*. Thus the impenetrability of matter was based on the sensation of touch; the geometrical properties of matter were abstracted from the visual sensations and the kinesthetic sensations of the eye-muscles. Not all the visual and tactile sensations were objectified; thus the sensations of color were excluded from physical nature as much as the sensations of dryness and moisture which Aristotle still objectified. It is clear that in accepting the distinction between primary and secondary qualities the physics of Galileo and Newton was consciously returning to the tradition of ancient atomism, i.e. to the corpuscular-kinetic model of nature. Its basic constituent ideas are:

1. Matter, which is discontinuous in its structure, moves through the Euclidian space according to the strict laws of mechanics.
2. All apparently qualitative differences in nature are merely surface effects of the difference of either motion or configuration of the basic units of matter.
3. All apparently qualitative changes are merely surface effects of the displacements of the same units.
4. All interaction between the basic particles is due exclusively to their direct contact. There is no action at a distance.
5. Qualitative varieties and qualitative changes are

https://doi.org/10.1177/039219216801606306 Published online by Cambridge University Press

in the perceiving human mind only; they do not have any objective status.

Time is lacking to consider the richness and fruitfulness of the classical scheme even in a cursory way. The whole history of physics from 1600-1900 bears an eloquent testimony about it. Only about sixty or seventy years ago, difficulties began to appear which grew in number and seriousness. But I would like to call attention to *one* point which was obscure *right* from the beginning. It was the *point five*: the status of secondary qualities and of qualities in general. They were *excluded* from the objective world; in this sense they were illusory. But what then was their status? Clearly they were regarded as existing in *some* sense; even an illusion must have some sort of status—if it did not exist, we should not worry about correcting it. There were two solutions, both *not* very satisfactory; the first one was to locate them outside of space in an unextended entity, in the "thinking substance," mysteriously associated despite its non-spatial character with a particular organism. This was the solution of Descartes; and *although* he was basically right in insisting that the introspective qualities cannot be denied without making a self-contradictory statement or, to use Professor Lovejoy's phrase, without creating a "*paradox of thinking behaviorist*,"[5] he was clearly helpless in trying to construct any rational model which would relate the qualitative realm of consciousness to the mechanistic realm of matter. The second solution was no solution *at all*: it consisted in a simple and flat denial of those qualities. The mental qualities, according to this view, do not exist because they do not fit into the mechanistic scheme and they are entirely superfluous. This was the solution proposed by materialists and behaviorists; it is very attractive by its simplicity and economy. But it *sins* by using an *Occam's razor* which is too sharp—so sharp that it cuts the very branch on which the materialists are sitting. For in no scientific or philosophical explanation should any fact, no matter how embarassing for the symmetry of the system, be simply suppressed. Consciousness cannot be suppressed for it reemerges in the very act by which it is denied. For

[5] A.O. Lovejoy, "The Paradox of Thinking Behaviorist," *The Philosophical Review*, XXXI (1922).

this reason a consistent behavioristic position is self-contradictory, as it always ends in the paradox of thinking behaviorist or in the absurdity of the self-denying thought. Even such a radical sceptic as Santayana conceded "the solipsis of the mental present" as the *only* absolute certainty.

It is true that there was the third solution which tried to reconcile the Cartesian certainty of introspection with the data of classical physics. This was the famous identity or double-aspect theory, first formulated by Spinoza, and later very popular in the second half of the last century and among positivists even today. In this theory, consciousness was not denied; but it was deprived of its causal efficacy. An embarassing question for this theory was: why the cosmic mechanism ever indulges in a very peculiar luxury to produce an idle entity of consciousness which does not interfere with the cerebral processes at all and consequently is entirely superfluous in the whole scheme of nature? It is strange that this view was and still is defended by positivists; apparently, in *their* view, nature itself ignores the rule of Occam in creating a completely idle and superfluous entity which we call "consciousness."

I purposely engaged in this digression to indicate that prior to 1900 the only doubts about the mechanistic scheme of nature were of *epistemological* kind. Some epistemological uneasiness was also felt about the famous distinction between the primary and secondary qualities. Is not the sensation of touch and hardness just *as subjective* as any other sensation? Why should we believe that the very nature of matter should disclose itself more adequately in the sensation of hardness rather than in the sensation of sound or scent? Is a solid atom, as Bergson asked a few years before the second scientific revolution began, anything more than an objectified sensation of touche?[6] But physicists themselves were naturally unconcerned about these questions and confidently and with great success extended the mechanization of the world picture *far* beyond the limits of physics. Darwin's explanation of evolution as a result of a mechanical sifting

[6] *Matière et mémoire*, 28th ed. (1934), p. 241: "Les atomes qui se poussent et s'entrechoquent ne sont point autre chose que les perceptions tactiles objectivées, détachées des autres perceptions en raison de l'importance exceptionnelle qu'on leur attribue, et érigées en réalités indépendantes..."

process by which the unsuitable incidental variations are eliminated so that only "the fittest survive" is as mechanistic in its spirit as the physiological psychology and cerebral reflexology of the nineteenth and twentieth centuries.

I purposefully spent so much time in describing the classical model of nature to convey the idea *what* is at stake when this model, so impressive by its unity and by its coherence is now shaken of its very foundations. Let us take the concepts of classical physics *one by one* to see how profoundly each of them was transformed. Let us begin with the concept of space. The space of the Newtonian physics was Euclidian, that is, infinite, infinitely divisible, absolute, i.e. independent of its physical content, and rigid, i.e., its structure was independent of time. The space of modern physics seems to have *the very opposite* features: it is only approximately Euclidian if we accept the general theory of relativity; in other words, the non-Euclidian curvature of space is practically negligible when we consider our biological surrounding or even our whole solar system; in the same way as a small portion of the spherical surface is flat, a small portion of the cosmic space is Euclidian. The space of modern physics, though still very, very large, is quite possibly finite, though without limits; although it can be subdivided into very small regions, very probably it is not infinitely divisible and the length of 10-13 cm may well be the smallest possible length. It is not absolute, i.e. independent of its physical content; if we accept the general theory of relativity, its relation to matter is not the relation of the container to its content, since matter itself, including its dynamic manifestations, is merged with the non-Euclidian structure of space. Finally, its structure is not rigid as that of the classical Newton-Euclidian space, but it varies from place to place and from time to time, not speaking of the over-all expansion of space which causes the recession of galaxies. But even prior to the general theory of relativity the inseparability of space from time found its expression in Lorentz transformation and Minkowski's formula for the world-interval.

From what I just said it is clear that the concept of matter was as much revised as that of space. The classical physics regarded matter as impenetrable and inert stuff occupying certain regions of space. But the general theory of relativity does *not* regard the relation of matter to space as that of the content to its container; matter is *fused* with the changing and locally variable structure of space-time. Thus the inertial or gravitational field—both being one and the same reality according to the principle of equivalence—should *not* be regarded as being *located* in the unchanging and physically indifferent Euclidian space-time. Energy and mass, which were traditionally separated, are now merged together according to the famous equation which the whole world knows: $E = mc^2$; and I do not need to refer to the spectacular way in which this equation was verified nearly twenty years ago. This equation tells us that every mass, even when completely at rest, possesses a tremendous energetic content; and that every energy, no matter how disembodied it may appear, has a tiny mass. It means that even the energy of radiation, having a certain mass, must exert a tiny pressure; and must be subject to the action of gravity; the first consequence was verified by the Russian physicist Lebedev even prior to the formulation of the special principle of relativity (1900), while the confirmation of the latter in 1919 made general relativity known to the wider public. It is thus conceivable that under certain conditions the whole mass may be converted into radiation or *vice versa*; this was indeed confirmed in 1932, when the positive electron was discovered. This particle is literally born out of gamma radiation together with a negative electron; thus the law of conservation of charge is *not* violated; neither is there any formal violation of the law of conservation of mass—for the mass of created particles in a sense preexisted in the "mass" of the radiation. The opposite phenomenon—the dematerialization of particles—was found at the same time, for a positive electron lives a very short time and disappears after one-hundred-millionth of a second. We really should not say "disappears" for, again, its mass is preserved in the "mass" of the radiation into which it is converted. Both the materialization and dematerialization of particles were *not* unexpected since they both exemplify the equivalence of mass and energy; but *what* was unexpected was the *alarming* rate with which more and more new particles were discovered so that Professor Oppenheimer, in 1955, could speak of the whole "sub-nuclear zoo."[7]

[7] Robert Oppenheimer, *The Constitution of Matter* (Condon Lectures, 1956).

https://doi.org/10.1177/039219216801606306 Published online by Cambridge University Press

Philosophically, the most interesting and also most puzzling feature of these recently discovered "particles" is that they are, strictly speaking, *no particles at all.* The word "particle" or "corpuscle" suggests something solid, unchangeable, and permanent: this was the connotation which this word had for Democritus, Lucretius, Gassendi, Newton, Dalton, Boltzmann, and even for Lorentz: something indestructible and uncreatable. How can such a word be meaningfully applied to these new strange entities some of which last only a trillionth or even a quadrillionth of second? Are we not stretching the meaning of the word "corpuscle" a bit too far when we apply it to such evanescent entities? Are we not simply yielding to the *sheer inertia* of our traditional language? Would not the term "event" be much more appropriate? Nothing illustrates more strikingly the profound difference between the rigid and permanent atoms of the classical kinetic view of nature and these new event-like entities which are born out of radiation and disappear in a puff of radiation and whose strange behavior is described by such terms as "*decay*" or "*multiplication*," which certainly would have made the great Newton shudder in disbelief. It may be objected that these strange entities possess the corpuscular character *at least* during their own short life. But even this is not true. For the word "particle" or "corpuscle" means—if it means anything at all—an association of two features: definite position and definite momentum. Yet, if we take Heisenberg's indeterminacy principle seriously, we cannot meaningfully speak of anything of this kind, not because anything of this kind *cannot be found* in nature, but because it does not *exist* in nature. Another article would be necessary to discuss two conflicting interpretations of the principle of indeterminacy and, because of the space limitation, I have to make a very concise and dogmatic-sounding statement: the hope that classical determinism and the classical corpuscular model will be recovered on the *sub-quantum level*, although not entirely unreasonable, seems to the majority of physicists *highly unrealistic*, especially when we realize that this hope is mainly due to the persistence of the traditional modes of thought.

What then is left of classical physics? Remember that we said it will always be taught on a high school level and in the elementary college courses for one simple reason: that the classical laws *are valid* in the world in which we live. And this undoubtedly accounts for the fact that classical physics, and the modes of thinking which characterize it, will *always* appear to the human mind as inherently more attractive and more natural. For our thinking draws *nearly all its material* from our sensory perception; and our sensory perception is *macroscopic.* In other words, what we perceive is *not* matter itself, *not* reality itself but the *macroscopic surface* of reality, or, to use Reichenbach's word, *the world of middle dimensions* which is situated half-way between the electrons and galaxies. We perceive only what has a biological importance for the preservation of individuals or species; for this reason it would be biologically uneconomic if we would perceive the vanishing non-Euclidian curvature of space or negligible microphysical indeterminacy. Although we know that solidity is not the attribute of the ultimate elements of the physical world, it still remains a *real quality* of our sensory perception which, so to speak, condenses into one single quality of touch an enormous number of the micro-physical events in a similar way as our sight condenses in a single quality of color an enormous number of successive electromagnetic vibrations. It would be thoroughly uneconomical if we would perceive each photon and each electron separately; thus the world of sensory perception is a *highly useful*, but also a *highly selective* simplification of the tremendously complex physical reality.

Out of this sensory perception grew classical physics and to a great extent classical philosophy. That classical physics was essentially the physics of solid bodies can hardly be doubted; the persistent tendency to reduce all phenomena to mechanics, i.e. to the motion of solid units, indicates it clearly. But what about classical philosophy? Certainly atomism was not the only philosophical tradition. But if we take into account how the traditional concept of Being developed from the Eleatic notion of the solid sphere; if we remember how the Being of philosophers shared its rigidity and its static character with the matter of Democritus and Newton; if we bear in mind the permanent fascination which this idea of rigid Being exerted on the imagination of philosophers from Parmenides to Sartres and Paul

https://doi.org/10.1177/039219216801606306 Published online by Cambridge University Press

Tillich—then perhaps Bergson's nearly forgotten claim that our logic is a *logic of solid bodies* would sound less strange. This is made even more probable by the following consideration: the mechanistic, i.e. corpuscular-kinetic model of nature remained amazingly successful *as long as* its application was confined to the world of middle dimensions, to the world of our daily life, to the world where the velocities are negligible, and the quantum discontinuities can be safely disregarded. Was not this success due to the fact that our thinking and imagination with its instinctive preferences for the atomistic and kinetic explanation was a *result of adjustement* to this middle sector of reality? And that the paradoxes and oddities which our imagination and even our thought faces are due to our instinctive attempt to apply our mechanistic modes of thought even *outside* of the area to which they were originally adjusted? Time is lacking to outline in a more detailed way *the biological theory of knowledge* which in my view is the only one explaining satisfactorily both the amazing fruitfulness and applicability of the mechanistic and visual models *within* certain ranges of experience and their complete failure and inadequacy *outside* of the same range.

But does not this sound rather discouraging and intellectually defeatistic? If our thought is hopelessly contaminated by our macroscopic perception, does it mean that it will be forever confined in its understanding to the world of middle dimensions? Certainly not. Although I said that our thought *is* macroscopically conditioned, I did *not* say that it is *hopelessly* so. The whole development of post-Newtonian physics indicates the very contrary. I do not mean only the fact that physicists are now so intellectually emancipated that they are not and will not be surprised by any new discovery, no matter how surprising and contrary to their intellectual habits it may be. This may be just an effect of a new habit; one eventually gets used to *everything*, even to the miraculous. And the state of *intellectual* apathy which is thus created may be even dangerous because it is incompatible with the capacity of wonder, of astonishment, which —in this respect I would side with Aristotle—is one of the basic presuppositions of philosophy, including philosophy of nature. What I mean is a wonderful flexibility of the mathematical formalism which helped the creators of the new theories in physics to free themselves of the exclusive sway of the Newton-Euclidian intellectual habits. Whether this will be sufficient remains to be seen. One can object that even the most abstract mathematics is not entirely free of the original biological tinge; does not the process of counting presuppose the permanence of the objects counted, as Helmholtz pointed out in one of his essays? And with regard to Georg Cantor's definition of *set* (in German *Menge*) as a "collection of definite and separate objects,"[8] it can hardly be denied that we can discern behind the apparently abstract concept of "object" its sensory root—a solid body of our macroscopic experience, the concept of which is so utterly inapplicable to microphysics. But we should not despair. Although our present thought even in its most abstract forms is conditioned by the macroscopic environment, it is never completely dependent on it. I find it highly significant that just about at the same time when modern physics was born—at the beginning of this century—psychologists rediscovered what they called *imageless thought* which clearly transcends the limits of sensory thought;[9] and it will be along the line of imageless thought that in my view—or should I say in my hope?—a deeper understanding of the paradoxical structure of matter will eventually be obtained.

One may ask: what practical significance can the second scientific revolution have besides the well known spectacular technological achievements which certainly are not an unmixed blessing? Such a question reflects the very widespread superficial view which tends to equate science with technology and which completely disregards intellectual curiosity which is the basic motive of any search for truth, whether in science or in philosophy. I can hardly imagine a *more* significant and *more* far-reaching intellectual event than what d'Abro called "the decline of mechanism" in physics. For *three* centuries the mechanistic view of nature ruled unchallenged; and for *more than two millennia* strict determinism, whether in its *theological* or *naturalistic* form, dominated the majority of the greatest minds. We are hardly in a position to measure adequately the implications and possible

[8] "bestimmte und wohlunterschiedene Objekte" in Georges Cantor's terminology.

[9] Alfred Binet's article "La pensée sans images," appeared in *Revue Philosophique*, 1903.

effects of the fact that mechanism as well as strict determinism are now *seriously* questioned within the science which was always regarded as the stronghold of both views.

Again I hear the objection: what *can* the revision of microphysical determinism conceivably have to *do* with determinism in biology, psychology, and social or, as it is fashionable to say today, behavioral sciences? Is not man a part of the world of middle dimensions where the statistical regularities of the microphysical processes converge asymptotically to the certainty of classical causality? Or in more simple words: is not the human and social realm, *even according to modern physics*, still ruled by strict determinism?

This, in my view, would be a dangerous half-truth. It is true that generally the indeterminacies of micro-events cancel each other in large macroscopic aggregates whose behavior thus can be described for all practical purposes by the classical deterministic laws. Only in such a way can the statistical laws of microphysics produce the orderly and almost strictly determined world of matter as we know it from our daily experience. But we must not overlook the *crucial* importance of the qualifying word "almost." We must not forget that, although the physical universe is made of heterogeneous strata—that is of the microcosmos, of the world of the middle dimensions, and of what may be called megacosmos—these strata are not separated by sharp boundaries and that they are in perpetual interaction. There is no question that under special conditions a microscopic indetermination can produce a spectacular effect in the world of the middle dimensions, possibly even on the astronomical scale. While this is rather an exceptional spontaneous occurrence in the inorganic world, it may be, according to some physicists and biologists, a regular occurrence in the organic bodies which were characterized by the physicist Pascual Jordan as "multiplicators of microphysical indetermination."

Jordan's hypothesis was much criticized by the positivists of the Vienna Circle, and their criticism was to some degree justified; for Jordan rather naïvely identified a single microphysical indeterminacy within the brain with free voluntary decision. On the other hand, it was fairly obvious that the generally hostile attitude of Jordan's critics was mainly due to their conscious or semi-conscious commitment to the mechanistic modes of thought. With the single exception of Reichenbach, all of them—Schlik, Zilsel, Frank—were made visibly unhappy by the very thought that the classical settlement of the controversy between determinism and indeterminism is perhaps not beyond dispute and that recent physics created the conditions for new solution.[10] To consider this possibility open-mindedly does not mean to be committed to Jordan's inadequate formulation. John Dewey, who certainly cannot be accused of supernaturalism, and who reacted very promptly to the discovery of the indeterminacy principle in his book *Quest for Certainty* (1929) formulated this view more cautiously in saying that microphysical indeterminacy is merely a necessary, though not sufficient, condition for freedom.[11] Is not angry impatience and intolerance which is shown—more by some philosophers than scientists—toward this idea a symptom—I would say almost a *psychoanalytical* symptom—of their unconscious loyalty to the nineteenth-century modes of thought?

I am only raising this question; I am only stating my personal belief that we are at the threshold of a new era in the intellectual history of mankind when we begin to guess only remotely the implications of the present upheaval in physics. Personally, I find fascinating the possibility that the era of our belief in psychological determinism and historical necessity, which was clearly a heritage of classical physics, is coming to an end. I am fascinated by the possibility that the era of mechanization of the world picture, by which the human mind was either eliminated or exiled into the limbo of casual inefficacy, is coming to an end. Mechanistic determinism had its positive effects in the increase of our control of physical nature; but in human affairs its influence was mostly disastrous. The superstition of historical inevitability produced—and still produces—two different effects both of which are clearly negative. The totalitarian movements of both rightist and leftist orientation cheerfully identified themselves with historical necessity. No *cliché* was more worn

[10] Jordan's articles appeared in *Naturwissenschaften*, XX (1932) and *Erkenntnis*, IV (1934), pp. 215-252; the resulting discussion in *Einheit der Wissenschaft* (1935), pp. 178-184.

[11] John Dewey, *The Quest for Certainty.* Gifford Lectures, 1929, Reprinted in 1960 in Capricorn Books (G.P. Putnam's Sons, New York), pp. 249-250.

out than that of the inevitable expansion and victory of the Nordic race as envisioned by Pangermanism and the Nazi racist theories; no cliché is today more tiresomely familiar than that of "the inevitable victory of scientific socialism" or "socialistic humanism"—which is neither scientific nor humanistic. It was not without reason that Karl Popper, who borrowed the term "open society" from Bergson while leaving out its philosophical context, dedicated his book, *The Poverty of Historicism*, to "all the victims of the superstition of historical determinism who died in the Nazi and Communist concentration camps." The attitude of democracy toward the same idea was not much different. Before the First World War Herbert Spencer identified the progressive democratization of mankind with allegedly inevitable progress, and this belief persists in spite of the tragic frustrations of both World Wars, in spite of the fact that the alleged historical inevitability brought about instead of a greater freedom the worst types of tyranny encountered in history. Yet, the superstition of historical necessity still dominates the leading minds of the Western world. Instead of questioning this superstition itself, they prefer to question the value of the democratic ideals and institutions; thus every expansion of tyranny is hailed as "a historically inevitable social development" while every opposition to it is cursed as an interference with the historical necessity itself—as if such necessity could be interfered with. It is time to realize that the road to democracy, that is, the transition from the closed to the open society, will not take place in a necessary inevitable way, but that it can be realized only by an *active effort* the result of which remains highly uncertain and is not sanctioned by any historical fatality. This should only increase our feeling of responsibility.

I am not making any dogmatic predictions about an inevitable coming of a certain type of philosophy; to make such a prediction would be incompatible with my disbelief in historical necessity. I mentioned some instances showing that anticipatory insights may be delayed by the natural inertia of human thought and may be even wilfully suppressed by the intervention of external authority. But as long as we succeed in keeping our open society, we should remain alert and keep our mind open to new and far-reaching implications of the second scientific revolution, no matter how sharply they may clash with the cultural heritage of the past.

https://doi.org/10.1177/039219216801606306 Published online by Cambridge University Press