ABSTRACTION AND SCIENCE

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THE man in the street to-day is aware that recent developments in the physical sciences have necessitated a fundamental revision of the concepts of physics; he finds that Einstein is no less upsetting to his ideas than was Copernicus to those of his own time or than Darwin was to Bishop Wilberforce. The plain man who has "philosophical leanings" is aware that questions previously regarded as metaphysical—and about which philosophers have written much that is unintelligible—are now recognized as falling within the scope of physics. Every reader of this *Journal* is aware that the criticism to which the main concepts of physics—space, time, matter—have been subjected is so fundamental that it is no longer possible to say that there are material bodies in space, which have events happening to them at a given time. We must substitute the conception of a fourfold continuum within which space, time and matter are inextricably involved. Finally, we are told that this new way of regarding the classical trinity suggests the consequence that we know nothing about the "inner nature" of the terms with which we deal, we can make no assertions as to the ultimate nature of that to which they may refer. In this respect the prevailing temper of the present-day scientist is to be contrasted with the cocksureness of most nineteenth-century physicists [1] who, even if they did not go so far as to say "we *know* what matter is," at least suggested that only the metaphysician had, or could have, any doubts as to its nature and reality. Thus, for instance, we find Thomson and Tait in their *Treatise on Natural Philosophy* asserting: "We cannot of course give a definition of *matter* which will satisfy the metaphysician, but the naturalist may be content to know matter as that which can be perceived by the senses, or as that which can be acted upon or can exert force. The latter, and indeed the former of these definitions, involves the idea of *force*, which in point of fact is a direct object of sense; probably of all our senses, and certainly of the 'muscular sense.'" [2] Tait, who seems to have combined a profound contempt for metaphysicians with a strong

[1] The term "nineteenth-century physicist" is possibly somewhat misleading. It is intended to indicate mainly Lord Kelvin, Tait, Tyndall and their disciples. It seems to me that the attitude of Maxwell was in important respects different from that of his contemporaries.

[2] *Treatise on Natural Philosophy*, vol. i, part i (ed. 1879), § 207.

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bias towards metaphysical speculations, reminds us that "we do not know, and are probably incapable of discovering, what matter *is*,"[1] and at the same time adopts the provisional definition: "*Matter is whatever can occupy space.*" Nor does he hesitate to assert that "The grand test of the reality of what we call matter, the proof that it has an objective existence, is its indestructibility and uncreatability—if the term may be used—by any process at the command of man."[2] But, except that this uncreatable and indestructible somewhat is said to have "an innate power of resisting external influences,"[3] it seems very closely to resemble Berkeley's unknowable substratum—the figment of philosophers. It is certainly clear that Tait and Thomson understood by *matter* something fundamentally different from an abstract construction. The first definition of matter given above occurs in a chapter on the principles of dynamics—a somewhat surprising context for such a definition. Even if these scientists of the nineteenth century would not have denied that the fundamental concepts, matter, mass, force, energy, as used in science, can be said to be known completely only in so far as they have just those properties that are assigned to them by the scientist; yet it cannot be doubted that they did for the most part believe that, when they were asserting the "reality of matter" and proclaiming its "objective existence," they were asserting something that was both true and important. Moreover, they did not believe that the test of this truth was to be found wholly in the *logical* fitness of these concepts. In asserting that matter was indestructible, Tait meant something more than the fact that "matter" is the result of a logical construction correlating observable data; he conceived its "indestructibility" as being quite different from the immutability of a logical function. "Nothing," say Thomson and Tait, "can be more fatal to progress than a too confident reliance on mathematical symbols; for the student is only too apt to take the easier course, and consider the *formula* and not the *fact* as the physical reality."[4] They would scarcely have admitted that matter is impenetrable *only because* whatever were not so would not be described as "matter."[5] It is not necessary to elaborate this point. Whatever part the nineteenth-century physicist ascribed to abstraction in scientific theory, he had an unshaken belief in what has been called the "billiard-ball view" of the universe, and he managed to combine a firm trust in sensation

[1] *The Properties of Matter*, § xx.

[2] *Recent Advances in Physical Science*, 1876, p. 14.

[3] *Treatise on Natural Philosophy*, § 216.

[4] *Ibid.*, p. viii.

[5] Cf. Tait: "Energy, like matter, has been experimentally proved to be indestructible and uncreatable by man. It exists, therefore, altogether independently of human senses and human reason, though it is known to man solely by their aid." (*Properties of Matter*, § 7; cf. also §§ 91–97.)

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as the basis of knowledge with the belief that only that which is independent of the "human senses" can be ultimately "real."

There are, it would seem, two opposed lines of thought. On the one hand abstract speculation reaching its most perfect form in mathematics leads to propositions every one of which is strictly deducible from other propositions, none of which can be said to be strictly "true" or "false," since "true" and "false" have primary reference to actual sense-experience. On the other hand we have actual experimental investigations based upon and throughout controlled by what is given in sense-experience. When an experimental physicist is working in his laboratory he observes something that is sensuously present to him. Probably many such observers share the plain man's belief that the physicist is dealing with "concrete facts," actualities given to him in his laboratory experiments. The experimental physicist might even repudiate with contempt the suggestion that he is concerned with "abstractions." Certainly physics starts from and returns to observable data. It is indeed Einstein's insistence that in the construction of a scientific theory only observable entities should be employed, that has rendered necessary the abandonment of the undetectable absolute space of Newton. An entity is observable when it can be defined in terms of physical measurements. The results of the calculations of the physicist appear on the one hand as verifiable experiments—data of sense; on the other, as extremely abstract theories. Thus Einstein's theory, which is the outcome of a rigorous refusal to admit non-observable entities, appears as excessively abstract when contrasted with, say, such a theory as Kelvin's vortex theory. It has little in common with theories of the "mechanical model" type, and is thus in marked contrast with the *kind* of theories preferred by the nineteenth-century physicists. But the phrase just used—"excessively abstract"—is likely to suggest an unclear opposition between "abstract theories" and "concrete facts," between "abstractions" and "experience." This vaguely felt opposition between obscurely apprehended terms is the main obstacle to the understanding of the function of abstraction in science. It is the main purpose of this article to discuss the meanings usually attributed to "abstraction" in this connection. The desirability of such a discussion becomes obvious when we contrast the outlook of Einstein and his contemporaries with that of the later nineteenth-century physicists. In this connection it is the change of *outlook* that is significant, a change that is revealed in the *kind* of explanation that would be acceptable to the latter but not to the former. Einstein has plainly shown that physics is a science of a high degree of abstraction, but this abstraction springs from a refusal to admit non-observable entities. Clearly many problems arise at this point as to the precise connection between physics and sense-perception, between geometrical space and perceivable space, between physics and geometry, which cannot be discussed within the limits of this article. But to elucidate the point reference may be made to Minkowski's famous *Address*, given at Cologne in September 1908. His problem was to show that, setting out from present-day mechanics, and proceeding along a purely mathematical line of thought, it is possible to arrive at changed ideas of space and time. Familiar though the famous opening sentence is, it may be worth while to quote it in order to emphasize the connection between the two aspects: "The views of space and time which I wish to lay before you have sprung from the soil of experimental physics, and therein lies their strength. They are radical. Henceforth space by itself and time by itself are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality." The significance of the first sentence must not be overlooked. Modern relativity physics requires us to believe that the entities with which science is concerned are much more "abstract" than the plain man or the older scientist could have believed to be possible. From the "soil of experimental physics" has sprung a theory in which "three-dimensional geometry becomes a chapter in four-dimensional physics"—a conception that made possible the work of Einstein. Clearly we must revise our notions of what we mean by "abstraction."

A final quotation from Minkowski's *Address* is relevant here. "The objects of our perception invariably include places and times in combination. Nobody has ever noticed a place except at a time, or a time except at a place. But I will respect the dogma that both space and time have independent significance. A point of space at a point of time, that is, a system of values x, y, z, t, I will call a *world-point*. The multiplicity of all thinkable x, y, z, t systems of values we will call *the world*. With this most valiant piece of chalk I might project upon the blackboard four world-axes. Since merely one chalky axis, as it is, consists of molecules all a-thrill, and, moreover, is taking part in the earth's travels in the universe, it already affords us ample scope for abstraction; the somewhat greater abstraction associated with the number four is for the mathematician no infliction. Not to leave a yawning void anywhere, we will imagine that everywhere and everywhen there is something perceptible. To avoid saying 'matter' or 'electricity,' I will use for this something the word 'substance.' We fix our attention on the substantial point which is at the world-point x, y, z, t, and imagine that we are able to recognize this substantial point at any other time. Let the variations dx, dy, dz, of

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the space coördinates of this substantial point correspond to a time element dt. Then we obtain as an image, so to speak, of the everlasting career of the substantial point, a curve in the world, a *world-line*, the points of which can be referred unequivocally to the parameter t from $-\infty$ to $+\infty$. The whole universe is seen to resolve itself into similar world-lines, and I would fain anticipate myself by saying that in my opinion physical laws might find their most perfect expression as reciprocal relations between these world-lines." I have quoted this passage at length because it shows clearly how much earlier Abstraction begins than is commonly supposed. No one who has reflected upon the work of Minkowski and its completion by Einstein can doubt that the entities with which the physicist deals are *abstracta*. Professor Whitehead had already pointed out, in 1906, that a construction of the concepts of the material world might be possible, in which construction there would be involved the assumption of " only one class of entities forming the universe. Properties of ' space ' and of the physical phenomena ' in space ' become simply the properties of this single class of entities." The ideal of such a procedure would be " to deduce some or all of the axioms required from more general axioms which would also embrace the laws of physics. Thus these laws should not presuppose geometry but create it." [1] It is a mathematician's ideal, but it is capable of leading to a theory that has its roots in " the soil of experimental physics." Popular views as to the relation of experiment to deduction, of " concrete " facts to " abstract " theory, certainly need revision.

Professor Whitehead, in a chapter dealing with Mathematics in relation to the sciences, has stated the position with his usual brevity: " The paradox is now fully established that the utmost abstractions are the true weapons with which to control our thought of concrete fact." [2] The value of the system thus obtained will depend first upon the adequacy of the *abstracta* used; secondly upon the resolute refusal to regard these abstracta as concrete. From the time of Newton the physicist working out in thought his control of the concrete fact has reached a conception of the universe " framed in terms of high abstractions " ; too often he has ended by mistaking these abstractions for concrete realities.[3] He has thereupon fallen into an error which Professor Whitehead has aptly named the " fallacy of Misplaced Concreteness." In the opinion of the present writer, Professor Whitehead has shown convincingly that the belief in the " simple location " of matter, in substance and in cause, results from a failure to recognize abstracta *as ab-*

[1] Whitehead, *Mathematical Concepts of the Material World. Philosophical Transactions*, vol. 205, A, p. 525.

[2] *Science and the Modern World*, p. 47. [3] *Ibid.*, p. 72.

stractions. It is not necessary to repeat his line of argument here. But it may be worth while to raise certain points which are scarcely discussed by Professor Whitehead—or are at least left in considerable obscurity.

What, we must first ask, is meant by "concreteness"? Unless we are clear about this we can scarcely expect to understand the function of abstraction. Two different answers might be given to this question: (1) *The concrete is the sensuously given*; it is that of which we are most certain in our ordinary life and in our laboratory. This is the practical, everyday meaning of "concrete"; it has essential connection with the familiar phrase, "Let us come to the concrete details." In this sense we talk of the concrete applications of a principle, or the formulation of a concrete scheme.[1] Along this line of thought we reach the conception of the concrete as the experimentally verifiable, thought to involve contact with the indubitably *real* because it is the immediately *given*. We are dealing with *facts* in Mr. Gradgrind's sense of "facts." (2) *The concrete is the synthesis of elements*; it is the complex of factors that are not found in isolation one from the other. The selection of an "aspect" is an abstraction from a concrete whole. An entity, or element, thus abstracted is what it is; it is not necessarily distorted by abstraction—indeed, were it distorted, something other than abstraction would be involved. Hence, we must decisively reject Bergson's view that abstraction involves falsification. It is primarily with reference to this second meaning of "concrete" that Whitehead speaks of *abstraction*. The two meanings are, as we shall see, connected; to show *how* they are connected is to explain the nature and function of abstraction in science.

The concrete is the sensuously given. But what is this? The answer can be nothing else than that it is an extended happening, an event. What is given is never a mere spatial extent, nor even a mere linear serial process of time, but a process of spatio-temporal happenings. There is a mode of approach to speculation on these topics from which this statement—a commonplace nowadays—seems so obviously true that we wonder how men of science so easily satisfied themselves with their abstractions that they were confident in their denial of everything not expressible in terms of momentary configurations of masses in motion. This is the mode of approach natural to human beings engaged in living. When the philosopher does not forget *himself*, he naturally starts with the complex happenings of that finite region of space wherein he is situated throughout a given, finite period of time. We have here what is ultimately concrete; it is, I think, what Whitehead calls the "actual occasion." This concreteness is an essential concretion; it has no definite

[1] Cf. J. M. Keynes, *Economic Consequences of the Peace*, p. 39.

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boundaries, and hence, it is not in any sense abstract. But just because abstraction is not involved, this concrete extended process is useless for the purposes of science, since science seeks the general, or universal, abstracted from the limitations of a given point of view.

It is, I believe, along this line of thought that it becomes possible to understand what Professor Whitehead means by *abstraction*, and in so doing to see more clearly the part played by abstraction in the scientific view of the world. It is not my purpose here to deal explicitly with Professor Whitehead's philosophy except in so far as it is relevant to this problem. He, more clearly than most writers on the philosophy of science, has seen the full significance of the function of abstraction in science and the necessity of relating this function to the rest of the world. In spite of the fact that the chapter on "Abstraction" in *Science and the Modern World* did not form part of the original Lowell Lectures, and seems almost to have been added to the book as an afterthought, it seems to me that the conception of abstraction is essential to Whitehead's conception of science. To understand his theory of events and objects it is essential to grasp the part abstraction plays in our apprehension of the external world.

Perhaps the key to Whitehead's conception of abstraction is to be found in a passage in *The Concept of Nature*, where he asserts: "The separate distinction of an entity in thought is not a metaphysical assertion, but a method of procedure necessary for the finite expression of individual propositions. Apart from entities, there could be no finite truths; they are the means by which the infinitude of irrelevance is kept out of thought."[1] It follows that "thought is wider than nature, so that there are entities for thought which are not natural entities." Two questions arise: (i) How are these "entities for thought" related to nature ?; (ii) How do they succeed in keeping out the infinitude of irrelevance ? A complete answer to (i) would require a discussion of the status of possibility in relation to the actual. This cannot be attempted here. It is sufficient to point out that 'the possible' is not related to 'the actual' as 'what could have happened' to 'what did happen.' The possible is a character of characters; the actual is a happening that is characterized. In the language of Professor Whitehead, the one falls on the side of "objects," the other on the side of "events." The answer to (ii) reveals the function of abstraction in science, which it is the purpose of this article to consider. The "infinitude of irrelevance" is excluded by abstraction of the relevant into a synthesis of aspects. The entity for thought—called sometimes a 'universal,' sometimes a 'concept,' and by Whitehead an "eternal object," is what it is in isolation from everything else. Since it

[1] *Loc. cit.*, p. 12.

is non-temporal, non-spatial, it can be thus isolated; it is not a happening and is completely what it is. In becoming related to a happening this entity is in no way modified, though the happening thereby becomes modified, and the modification takes the form of an essential limitation. This limitation involves abstraction.

Confusion is apt to arise here because the *abstract* is often regarded as the opposite not of the *concrete* but of the *real*; hence abstracta come to be thought of as in some sense "unreal." But we add nothing when we add the adjective "real." That in which we are interested is *real*, and the opposite of "real" in this connection is "imaginary." We need not proceed to ask: What is the "imaginary"? The plain man—to whom this article is addressed—attaches a perfectly definite meaning to the statement "So-and-so is imaginary," and the plain man's meaning is what the scientist means, though they would differ in their analysis. So, too, we can all understand some clear sense in which the after-image of a bright light is said "not to be *really* on the ceiling," where it has been projected. A careful examination of this meaning shows that the criterion of "real" is (i) observed by all observers; (ii) measurable.[1] In this sense the abstracta of science are real; but they are not concrete. So long as we keep to the standpoint of this earth and of human beings in their ordinary sense-experiences, we find agreement with regard to measurements. It is the discovery that other observers in very different circumstances would make very different measurements from those that would be expected, even when the difference in the circumstances has been taken into account, that has necessitated the theory of Relativity, and has made us more keenly aware of the extent to which the external world is an abstraction. The world as Minkowski and Einstein have conceived it is not *unreal* because it is abstracted from the local conditions and the personal peculiarities of terrestrial observers. But it is *abstract*. Its externality depends upon its abstractness. "The external world," Professor Eddington has said, "is the common element abstracted from the experiences of individuals in all variety of physical circumstances."[2] It is "a synthesis of appearances from all possible points of view." There is a double use of abstraction here. First, there is that particular abstraction that is involved in the standpoint of *one* observer, the privileged individual who is myself—an element never found in isolation but treated as such. This abstraction is superseded by a more complete abstraction secured by the adoption of a position abstracted from *all particular* observers, the standpoint of what might almost be called an observer

[1] Hence, Poincaré's phrase "Normal objectivity," and Planck's dictum, "The real is the measurable."

[2] *Science, Religion and Reality*, p. 196; cf. p. 193.

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of the universe, a non-individual observer. From such a standpoint statements can be made that are true for "all observers" because independent of any *given* point of view. By the adoption of such a standpoint the "infinitude of irrelevance" is excluded.

If, now, we look at it from the point of view of a given individual, we find a curious intermingling of the abstract and the concrete. The individual, in so far as he is a limited or finite part of the whole complex, situated at one given point of view, is himself an *abstractum*; but in so far as he occupies the immediate occasion he is concrete. In seeking a common, and therefore external, world, he achieves a synthesis of all possible points of view. He attempts—if we may so put it—*not* to be an abstractum, but he achieves the synthesis only by an abstraction from particular points of view, from the "infinitude of irrelevance" that is the mark of the immediate occasion. It is not to be wondered at that once the synthesis is achieved it is taken for a *concrete* reality. That it is *both* real *and* abstract is forgotten. Hence, the significance of abstraction is obscured. But, as Minkowski pointed out in the passage quoted above, a chalk line on a blackboard "already affords us ample scope for abstraction," differing only in degree from the abstraction of the mathematician.

Why, we ask, does the chalk line, or the piece of chalk, or at least the blackboard, seem to us *concrete* in an important sense of concrete which the plain man would probably express by calling it "substantial"? The answer is that the chalk we see, or touch, is believed to be concrete, or a "substance," because we have forgotten, or ignored its essential relations to ourself and to other things, i.e. because we have *abstracted it from its situation.* This process of first abstracting an entity, by ignoring essential relations so as to secure a common world, and then substantializing it, has been expressed in the development of language which has given "substantive" form to the *abstractum.* In turn the linguistic substantive has been regarded as a metaphysical substance as well as a logical subject. Thus language, practical utility and common sense have combined to produce the "fallacy of misplaced concreteness." This fallacy is the result of a mode of thinking that has penetrated very deeply into all our habits of thought, our common-sense beliefs and our science. Hence, Whitehead's assertion that all particulars are abstractions is apt to be regarded with surprised dissent.[1] The particular involves the minimum degree of abstraction from an actual occasion; the "synthesis of all possible points of view"—the standpoint of the observer of the universe—involves the maximum degree of abstraction in the same direction.[2] Science

[1] *The Concept of Nature,* p. 163. *Uniformity and Contingency,* p. 9.
[2] Cf. *Science and the Modern World,* p. 238.

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thus deals with abstracta of a high degree of abstractness, which are nevertheless in essential connexions with the sensuously observable, the empirically verifiable.

Hence, the function of abstraction in Science can be determined. Science abstracts in order to obtain a universal standpoint so that an external world may be secured. Externality is thus essentially bound up with the repudiation of the individual standpoint. That which is individual can only be "lived through"; it cannot, therefore, be communicated; hence, it is alien to scientific knowledge. Science must in some sense transcend the individual passing and seek the permanent in the flux of events. By abstraction science transcends the limitation of the *here-now* of any, and therefore of every, individual occasion; in so doing it can predict the past and the future.[1] Science is as such abstract, and the "reality" it contemplates is of the utmost degree of abstraction from the actual occasion. Through its abstractions we are supplied with "weapons with which to control our thought of concrete fact."[2]

In what respects, we may ask finally, does this conclusion suggest an outlook that is different from the outlook of nineteenth-century scientists? The difference is surely to be found in a fundamental change of attitude, which might almost be expressed as an awareness to-day of the greater significance of what is merely possible, which awareness is intimately connected with the realization of the precise nature of abstraction. We have seen that Kelvin and his collaborator Tait *meant* by "objectively real" something that, because it was "independent of all human senses," could *be* no matter what else was *not*. Matter as they conceived it was not unlike the substance of Descartes which required nothing else in order that it might exist. Matter was regarded as permanent in the sense of enduring through all time imperishably itself. It was, in the most obvious sense, the stuff out of which the universe was made, or *of* which the universe consisted. This conception, I venture to think, is wholly inconsistent with the modern scientific outlook. The permanence of matter is the permanence of a character; it is not the permanence of substance, nor of an enduring entity; moreover, a character could not be, if all else were not. A "bit of matter," a piece of material, cannot be conceived as an ultimate particle, an incompressible atom, or a collection of incompressible atoms. Nor, it seems to me, must it be conceived as a "logical fiction." Its reality is the reality of a permanent character.

The substitution of space-time for space and time forces us to

[1] From this standpoint the difference of past and future is a local difference; hence, apart from etymological objections, the scientist can be said to "predict the past."

[2] See p. 32 above.

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recognize the event, a spatio-temporal happening, as fundamental, as "in some sense the ultimate substance of nature."[1] But the conception of the "event" does not merely replace the traditional conception of "matter" for two reasons. First, "matter" was conceived as capable of existing at an instant, whereas the event is essentially passing; secondly, the event *as such* has no character by which it could become the object of scientific thought, whereas "matter" was conceived as having just those properties suited to control the practical experience of the physicist. These properties, however, did not include the "secondary qualities," although they included the so-called "primary qualities." If we accept the event as fundamental, we must also accept those characters of the event which make abstraction possible. These are what Whitehead calls "objects"; the atoms of traditional physics are recognized by him to be scientific *objects*. His protest against the extrusion of the "secondary qualities" from nature seems to me a return to the actual practice of the physicist. He neglects the *redness* of red light because what he measures is the *wave-length*; but he could not advance a step unless he *recognized* the redness. We have already referred to the conception of the real as the measurable; but *this* real is an abstraction no less than redness is.

The fact that science is essentially abstract has an important consequence. There are various modes of abstraction and different routes of analysis; corresponding to these various modes are different scientific schemes or conceptions. In so far as any of these schemes is capable of experimental verification, it is true and adequate as far as it goes. We may contrast the difference between the Ptolemaic Scheme and the Copernican with the difference between Newton and Einstein. The contrast is significant. Ptolemy and Copernicus differ mainly in the relative simplicity of their schemes; Newton and Einstein differ not only in this respect—great as this difference is; they differ also in the nature of the fundamental entities employed; hence the effect of the *total* conception of the universe is very different in these two cases. But the test of every scientific theory is always: Does it lead to *this* given particular experience? If so, it is so far true; if not, it is false and inadequate. The adequacy of the abstractions reached along one route of analysis must not blind us to the possibility of other abstractions, alike equally real and, for its given purpose, equally important. It is the recognition of this that makes the "cocksureness" of the nineteenth-century physicist out of date to-day.

[1] *The Concept of Nature*, p. 19.