

Arbitrariness in Physics

To what extent is physics a body of external truth independent of the student, and to what extent is it a set of man-made constructs that describe the world as we find it?

by R. Bruce Lindsay

WHAT IS SCIENCE? Briefly it is a way of talking about human experience with gestures. Talking makes all that happens in our daily lives intelligible to ourselves and others; gestures are overt activities by which we attempt to manipulate our experience into more tractable form. They are the operators by which we carry out our experiments. Science is a game in which we pretend that things are not wholly what they seem in order that we may make sense out of them in terms of mental processes peculiar to us as human beings. To approach an assessment of science less flippantly and with more modesty about its relation to other ways of coping with experience, we may say that science is a method for the *description, creation and understanding* of human experience, in which "experience" means the sum total of everything that happens to us in life plus our reflections on these things with our minds.

Psychology of physics

Science, or more accurately, the scientist describes by seeking order or regularities in experience and talking about them as simply as possible. This description reaches its culmination in scientific law, a succinct statement, usually in mathematical form, of a routine of experience—for example, Boyle's law as descriptive of the regu-

lar behavior of gases. Science creates experience through experimentation that supplements passive observation of the environment with active involvement, manipulating the elements of experience in carefully controlled fashion to see what happens. In this way new experience is brought to light. Finally science strives to understand by the construction of theories, which are imaginative pictures of things as they might be, and, if they were, they would lead logically to that which we find in actual experience. The great theories of science such as the theory of quantum mechanics in physics not only subsume in one set of constructs a vast domain of experience but also predict hitherto unknown experience and hence expand knowledge.

In the whole gamut of scientific method, the role of theory—particularly in physics—offers the most tantalizing problems to the philosopher of science. The logical structure of theories with their basic and derived constructs, their hypotheses and derived laws, has engaged the attention of many profound and some not-so-profound thinkers, and it may fairly be said that we now have a rather clear conception of how theories are put together.

What may appropriately be called the psychological analysis of the process of theorizing is, however, another

matter. Here not too much headway has been made, for the task is difficult. Questions to face are these: What leads a scientist to decide to study a particular facet of experience and what makes him adopt a particular method or point of view with the assurance that it is the correct way to understand this element of experience? For example, why did Aristotle esteem motion of such fundamental importance that he devoted much theorizing to it while Archimedes, his successor by nearly a century and usually regarded as a much more successful physicist, carefully avoided this aspect of experience in his theory building even though he used motion in a very practical way in the catapults he directed against the Roman fleet. Wherever we turn in the history of physics we find this selective tendency among those who have created the science. Some Greeks thought atoms were the ultimate answer to the problem of the

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constitution of matter, but Aristotle certainly did not. The reason for his attitude is usually attributed to his disbelief in the existence of a vacuum. Why was this? How attractive it would be if we could have old Aristotle back with us so as really to quiz him thoroughly about the real basis of his ideas! And yet it might, after all, be in vain. Many modern physicists who have tried to make clear the mental processes that went into their clever inventions have not succeeded too well.

Recently a renewal of interest in the psychology of physics has been pur-

sued rather vigorously, interestingly enough, in France. Perhaps this is appropriate since Henri Poincaré gave some attention to it early in the century. More recently the mathematician Jaques Hadamard¹ wrote an interesting and rather detailed book on the subject, including references to Poincaré's "flashes of illumination." Other French scientists who have studied it lately include René Taton² and Abraham Moles.³ In the US the psychologist Herbert Simon⁴ of the Carnegie Institute of Technology has begun to attack the matter with a

theory of problem solving. Inevitably progress will ultimately ensue though it may be slow. Psychologists with an interest in and a good grasp of the history and philosophy of physics could make an important contribution to this problem.

Discovery or invention?

The reason I have indulged in these comments on what may properly be called the psychology of physics is that they supply a fitting introduction to the main theme of the paper, namely, arbitrariness in physics. Just what do we mean by the term in the present context? We mean the completely free use of preference when choosing the experience to study and the equally free choice when constructing concepts and hypotheses to serve as the bases of theories. By stressing the physicist's freedom in this respect we are essentially viewing the purpose of physics as a scientific discipline as *invention* rather than *discovery*. Let us try to make this concept clear. Application of the term "discovery" implies that there is an external world "out there," wholly independent of the observer and with built-in regularities and laws waiting to be uncovered and revealed: They have always been there and presumably always will be; our task is by diligent search to find out what they are. On the other hand the term "invention" implies that the physicist uses not only his observations but his imaginative powers to construct points of view that identify with experience.

Interpretation of physics in terms of discovery means that the science is essentially a cumulative process. It is analogous to building an edifice: We lay one stone on another in turn and expect that eventually the building will be finished. Or, to put the matter another way, if physics is essentially discovery, we are entitled to the hope that in time we shall arrive at the *ultimate truth*, that we shall then know all that is possible to know about our world and our understanding will be complete. However, the point of view of invention means that the process of creating new experience and the construction of new ideas to cope with this experience constantly go hand in hand. The whole activity is open ended: The notion of complete-



GALILEO: "This idea (instantaneous velocity) appeared so arbitrary and unreasonable to many of his contemporaries that they would not accept it."



HISTORIES of Poincaré (left), Maxwell and Faraday contain workable examples of arbitrariness.

ness has no place in it whatever.

If the conception that physics is essentially an arbitrary discipline thus comes down rather heavily on the side of invention as against discovery, is it not true that there is much to say on the other side also? Certainly many of the physicists of the 19th century had a strong feeling that they were "discovering" what was "really there" and that the *final* truth was only around the corner. To many it appeared that the atomic point of view combined with the electromagnetic-field concept was on the way to providing the ultimate explanation. To us today it is difficult to understand why they were so unprepared for the jolt that came with the invention of the quantum theory and relativity. And yet if they had only been willing to restrain their curiosity about the peculiarities of thermal radiation and the discharge of electricity through gases at low pressure, they might have retained their sublime confidence a bit longer. But the game had to go on—though even the creator of quantum theory himself was not happy over his accomplishment.

The thesis of arbitrariness in physics as against what may be called the "ultimate truth" point of view is closely connected with what philosophers have long considered to be the most serious

problem in the nature of science, namely, the validity of scientific inference. It is on this problem that David Hume employed his Scottish scepticism in devastating fashion. He viewed it in this simple way: How can we gain *knowledge* of that which has not been observed? Hume could see no sure way to an unambiguous successful inference of future experience on the basis of induction from past and present experience. Some philosophers have concluded that this notion destroys the validity of science as a discipline; for it means that we can never be sure that the predictions deduced from the postulates of a scientific theory, even if once verified, will continue to be verified.⁵ Now undoubtedly Hume's scepticism carried great weight when the concepts and hypotheses of scientific theories were supposedly suggested inductively by actual experience, or when it was believed that these categories were "discovered" from this experience. It must be confessed that such considerations no longer disconcert the present-day scientist and in particular the physicist, who has developed his own criteria for the success of theories and has found that theories with *arbitrarily* chosen postulates often satisfy those criteria. To him this is sufficient as a pragmatic justification of what he

does. Moreover a study of the history of physics appears to confirm the suspicion that emphasis on the importance of induction when formulating physical theories has been rather overrated in earlier times. The element of arbitrariness has entered more often than has been realized or admitted. A good example is Galileo's introduction of the concept of instantaneous velocity in the development of the theory of mechanics. This idea appeared so arbitrary and unreasonable to many of his contemporaries that they would not accept it.

Objections and replies

As I have already suggested, it is not difficult to raise objections to the idea that physics is an arbitrary science. One can maintain with some plausibility that early physics (that is, physics in ancient and medieval times) did not show this characteristic of arbitrariness. Did not our early predecessors investigate all the things that are actually in evidence instead of picking and choosing to suit themselves, and did they not go about explaining these things in the most obvious fashion? The history of physics unfortunately shows that this is an oversimplified and distorted point of view. We have already mentioned Aristotle and Archimedes in contrasting the choice of

material for study that they considered interesting. Moreover, they followed different methods: Aristotle laid great emphasis on taxonomy, whereas Archimedes employed mathematical analysis with considerable success. The essence of this illustration can be duplicated many times in the historical development of physics, particularly in connection with the arbitrary ways in which physicists have sought to explain the experience they found of interest. One has merely to contemplate among others the vigorous controversies that have marked attempts to understand the constitution of matter (atomic versus continuum point of view), the nature of heat (caloric versus mechanical theory), and the nature of light (corpuscular versus wave theory). Certainly what seemed an obviously correct explanation to one thinker was not at all obvious to another.

Of course one can cite counter examples of physicists who felt that it was perfectly clear what they were called on to do and that there was little arbitrariness in their choice. Faraday, for example, certainly had plausibility on his side when he decided to devote his attention to uncovering relations among what were considered in his time disparate phenomena like electricity and magnetism, electricity and light, gravitation and electricity, etc. There was nothing rampantly imaginative about this program. It possessed an air of obviousness, and it surely paid off. On the other hand, Maxwell's invention of the displacement current, which led directly to his prediction of electromagnetic waves, was a bold and arbitrary extrapolation, not too enthusiastically received by his contemporaries. Lord Kelvin never felt happy about it. But it foreshadowed a program in theory building that has become a commonplace of our day in which arbitrary abstract constructs and postulates are freely introduced in the building of physical theories. This is adequately exemplified in the formal structure of quantum mechanics with its complete revision of the classical concept of a system's state in the introduction of the ψ function. Nuclear physics, with its concern for nuclear structure and the many so-called elementary particles, is providing an even more exag-

gerated illustration of the arbitrary use of the imagination in constructing abstract structures. So far has this process gone in the case of the so-called S-matrix formulation that it has been seriously suggested that the concept of the space-time continuum, hitherto the basic substructure of all physical theorizing, should be given up entirely.⁶ Nothing in this notion should make the physicist's flesh creep: It is merely the natural extrapolation of a process that has marked the progress of physics as a science from the beginning. The clever physicist will always reserve the right to invent in arbitrary fashion the constructs he deems likely to succeed in the theoretical explanation of experience, even if this leads to rather bizarre devices for identifying these constructs with observational data.

Sociology of physics

We might well leave our brief examination of arbitrariness in physics at this point. But further reflection suggests that there may be significant implications for what may be called the sociology of physics. The arbitrary choice of the 19th century physicists forced the direction of physical research even more intensively into electrical phenomena. To most people today this appears to have been such an obvious development that things could have scarcely worked out otherwise, and yet candor insists that they might well have done so. Physical and life sciences might have got together earlier, and there could have been more intensive research stimulated on the relation between light and the eye and between the ear and sound. As it was, physicists preferred the electrical route with results that have colored the whole growth of contemporary physics. One practical result has been the relegation, in the minds of many physicists, of disciplines such as optics, acoustics and hydrodynamics to the status of technology with assurance (not well founded to be sure) that no more basic physics can be squeezed out of them. This idea might be dismissed as a mere aberration of fashion, but it may have serious consequences in terms of financial support for physics research. In earlier times this state of affairs would not have been true since physical research

was comparatively inexpensive and physicists investigated pretty much what their curiosity suggested, undeterred by consideration of support. This situation no longer exists. Most modern research in physics demands large expenditures of money that must, in general, be obtained from those who have it, namely, the large foundations and the government. This arrangement in turn demands more or less elaborate justification of the research effort, involving appraisal of research proposals by review boards. In making their decisions the latter must depend on the opinion of the "experts." The circular character of this business is evident without further discussion. The only reason most of us hesitate to term it vicious is that we feel the necessity of breaking into the circle to have the chance of carrying out our own research plans.

The arbitrariness in physics that has led to the research-support problem just mentioned does indeed carry a certain self-corrective in the variety of problems that suggest themselves to clever people. This may well be the saving factor in the situation. The very proliferation of interest manifested in the development of space research as well as that now mushrooming in the biophysical and psychophysical fields may prevent the bias toward nuclear and solid-state physics from becoming crucial. But the very existence of arbitrariness in science should warn all thoughtful scientists to be on their guard against the growth of that dogmatism which is the great enemy of scientific advance.

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