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What Is Science?

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To answer the question "What is science?" is almost as presumptuous as to try to state the meaning of life itself. Science has become a major part of the stock of our minds; its products are the furniture of our surroundings. We must accept it, as the good lady of the fable is said to have agreed to accept the Universe.

Yet the question is puzzling rather than mysterious. Science is very clearly a conscious artifact of mankind, with well-documented historical origins, with a definable scope and content, and with recognizable professional practitioners and exponents. The task of defining poetry, say, whose subject matter is by common consent ineffable, must be self-defeating. Poetry has no rules, no method, no graduate schools, no logic: the bards are self-anointed and their spirit bloweth where it listeth. Science, by contrast, is rigorous, methodical, academic, logical, and practical. The very facility that it gives us, of clear understanding, of seeing things sharply in focus, makes us feel that the instrument itself is very real and hard and definite. Surely we can state, in a few words, its essential nature.

It is not difficult to state the order of being to which science belongs. It is one of the categories of the intellectual commentary that man makes on his world. Amongst its kith and kin we would put religion, art, poetry, law, philosophy, technology, etc.—the familiar divisions or "faculties" of the academy or the multiversity.

At this stage I do not mean to analyze the precise relationship that exists between science and each of these cognate modes of thought; I am merely asserting that they are on all fours with one another. It makes some sort of sense (though it may not always be stating a truth) to substitute these words for one another, in phrases like "Science teaches us . . ." or "The Spirit of Law is . . ." or "*Technology* benefits mankind by . . ."or "He is a student of *Philosophy.*" The famous "conflict between Science and Religion" was truly a battle between combatants of the same species—between David and Goliath if you will—and not, say, between the Philistine army and a Dryad, or between a point of order and a postage stamp.

Science is obviously like religion, law, philosophy, and so forth in being a more or less coherent set of ideas. In its own technical language, science is information; it does not act directly on the body; it speaks to the mind. Religion and poetry, we may concede, speak also to the emotions, and the statements of art can seldom be written or expressed verbally—but they all belong in the nonmaterial realm.

But in what ways are these forms of knowledge *unlike* one another? What are the special attributes of science? What is the criterion for drawing lines of demarcation about it, to distinguish it from philosophy, or from technology, or from poetry?

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One can be zealous for science, and a splendidly successful research worker, without pretending to a clear and certain notion of what science really is. In practice it does not seem to matter.

Perhaps this is healthy. A deep interest in theology is not welcome in the average churchgoer, and the ordinary taxpayer should not really concern himself about the nature of sovereignty or the merits of bicameral legislatures. Even though church and state depend, in the end, upon such abstract matters, we may reasonably leave them to the experts if all goes smoothly. The average scientist will say that he knows from experience and common sense what he is doing, and so long as he is not striking too deeply into the foundations of knowledge he is content to leave the highly technical discussion of the nature of science to those self-appointed authorities the philosophers of science. A rough and ready conventional wisdom will see him through.

Yet in a way this neglect of—even scorn for—the philosophy of science by professional scientists is strange. They are, after all, engaged in a very difficult, rather abstract, highly intellectual activity and need all the guidance they can get from general theory. We may agree that the general principles may not in practice be very helpful, but we might have thought that at least they would be taught to young scientists in training, just as medical students are taught physiology and budding administrators were once encouraged to acquaint themselves with Plato's *Republic*. When the student graduates and goes into a laboratory, how will he know what to do to make scientific discoveries if he has not been taught the distinction between a scientific theory and a nonscientific one? Making all allowances for the initial prejudice of scientists against speculative philosophy, and for the outmoded assumption that certain general ideas would communicate themselves to the educated and cultured man without specific instruction, I find this an odd and significant phenomenon.

The fact is that scientific investigation, as distinct from the theoretical content of any given branch of science, is a practical art. It is not learnt out of books, but by imitation and experience. Research workers are trained by apprenticeship, by working for their Ph.D.'s under the supervision of more experienced scholars, not by attending courses in the metaphysics of physics. The graduate student is given his "problem": "You might have a look at the effect of pressure on the band structure of the III-V compounds; I don't think it has been done yet, and it would be interesting to see whether it fits into the pseudopotential theory." Then, with considerable help, encouragement, and criticism, he sets up his apparatus, makes his measurements, performs his calculations, et cetera and in due course writes a thesis and is accounted a qualified professional. But notice that he will not at any time have been made to study formal logic, nor will he be expected to defend his thesis in a step by step deductive procedure. His examiners may ask him why he had made some particular assertion in the course of his argument, or they may enquire as to the reliability of some particular measurement. They may even ask him to assess the value of the "contribution" he has made to the subject as a whole. But they will not ask him to give any opinion as to whether physics is ultimately *true,* or whether he is justified now in believing in an external world, or in what sense a theory is verified by the observation of favorable instances. The examiners will assume that the candidate shares with them the common language and principles of their discipline. No scientist really doubts that theories are verified by observation, any more than a common law judge hesitates to rule that hearsay evidence is inadmissible.

What one finds in practice is that scientific argument, written or spoken, is not very complex or logically precise. The terms and concepts that are used may be extremely subtle and technical, but they are put together in quite simple logical forms, with expressed or implied relations as the machinery of deduction. It is very seldom that one uses the more sophisticated types of proof used in mathematics, such as asserting a proposition by proving that its negation implies a contradiction. Of course actual mathematical or numerical analysis of data may carry the deduction through many steps, but the symbolic machinery of algebra and the electronic circuits of the computer are then relied on to keep the argument straight.[1] In my own experience, one more often detects elementary non sequiturs in the verbal reasoning than actual mathematical mistakes in the calculations that accompany them. This is not said to disparage the intellectual powers of scientists; I mean simply that the reasoning used in scientific papers is not very different from what we should use in an everyday careful discussion of an everyday problem.

. . . [This point] is made to emphasize the inadequacy of the "logico-inductive" metaphysic of science. How can this be correct, when few scientists are interested in or understand it, and none ever uses it explicitly in his work? But then if science is distinguished from other intellectual disciplines neither by a particular style or argument nor by a definable subject matter, what is it?

The answer proposed in this essay is suggested by its title: *Science is Public Knowledge*. This is, of course, a very cryptic definition, with almost the suggestion of a play upon words. What I mean is something along the following lines. Science is not merely *published* knowledge or information. Anyone may make an observation, or conceive a hypothesis, and if he has the financial means, get it printed and distributed for other persons to read. Scientific knowledge is more than this. Its facts and theories must survive a period of critical study and testing by other competent and disinterested individuals, and must have been found so persuasive that they are almost universally accepted. The objective of science is not just to acquire information nor to utter all noncontradictory notions; its goal is a consensus of rational opinion over the widest possible field.

In a sense, this is so obvious and well-known that it scarcely needs saying. Most educated and informed people agree that science is true, and therefore impossible to gainsay. But I assert my definition much more positively; this is the basic principle upon which science is founded. It is not a subsidiary consequence of the "scientific method"; it *is* the scientific method itself.

The defect of the conventional philosophical approach to science is that it considers only two terms in the equation. The scientist is seen as an individual, pursuing a somewhat one-sided dialogue with taciturn nature. *He* observes phenomena, notices regularities, arrives at generalizations, deduces consequences, et cetera and eventually, Hey Presto! a law of nature springs into being. But it is not like that at all. The scientific enterprise is corporate. It is not merely, in Newton's incomparable phrase, that one stands on the shoulders of giants, and hence can see a little farther. Every scientist sees through his own eyes—and also through the eyes of his predecessors and colleagues. It is never one individual that goes through all the steps in the logico-inductive chain; it is a group of individuals, dividing their labor but continuously and jealously checking each other's contributions. The cliché of scientific prose betrays itself "Hence we arrive at the conclusion that . . ." The audience to which scientific publications are addressed is not passive; by its cheering or booing, its bouquets or brickbats, it actively controls the substance of the communications that it receives.

In other words, scientific research is a social activity. Technology, art, and religion are perhaps possible for Robinson Crusoe, but law and science are not. To understand the nature of science, we must look at the way in which scientists behave toward one another, how they are organized, and how information passes between them. The young scientist does not study formal logic, but he learns by imitation and experience a number of conventions that embody strong social relationships. In the language of sociology, he learns to play his *role* in a system by which knowledge is acquired, sifted, and eventually made public property.

It has, of course, long been recognized that science is peculiar in its origins to the civilization of Western Europe. The question of the social basis of science, and its relations to other organizations and institutions of our way of life, is much debated. Is it a consequence of the "Bourgeois Revolution," or of

Protestantism—or what? Does it exist despite the Church and the universities, or because of them? Why did China, with its immense technological and intellectual resources, not develop the same system? What should be the status of the scientific worker in an advanced society; should he be a paid employee, with a prescribed field of study, or an aristocratic dilettante? How should decisions be taken about expenditure on research? And so on.

These problems, profoundly sociological, historical, and political though they may be, are not quite what I have in mind. Only too often the element in the argument that gets the least analysis is the actual institution about which the whole discussion hinges—scientific activity itself. To give a contemporary example, there is much talk nowadays about the importance of creating more effective systems for storing and indexing scientific literature, so that every scientist can very quickly become aware of the relevant work of every other scientist in his field. This recognizes that publication is important, but the discussion usually betrays an absence of careful thought about the part that conventional systems of scientific communication play in sifting and sorting the material that they handle. Or again, the problem of why Greek science never finally took off from its brilliant taxying runs is discussed in terms of, say, the aristocratic citizen despising the servile labor of practical experiment, when it might have been due to the absence of just such a communications system between scholars as was provided in the Renaissance by alphabetic printing. The internal sociological analysis of science itself is a necessary preliminary to the study of the sociology of knowledge in the secular world.

The present essay cannot pretend to deal with all such questions. The "science of science" is a vast topic, with many aspects. The very core of so many difficulties is suggested by my present argument—that science stands in the region where the intellectual, the psychological, and the sociological coordinate axes intersect. It is knowledge, therefore intellectual, conceptual, and abstract. It is inevitably created by individual men and women, and therefore has a strong psychological aspect. It is public, and therefore molded and determined by the social relations between individuals. To keep all these aspects in view simultaneously, and to appreciate their hidden connections, is not at all easy.

It has been put to me that one should in fact distinguish carefully between science as a body of knowledge, science as what scientists do, and science as a social institution. This is precisely the sort of distinction that one must not make; in the language of geometry, a solid object cannot be reconstructed from its projections upon the separate Cartesian planes. By assigning the intellectual aspects of science to the professional philosophers we make of it an arid exercise in logic; by allowing the psychologists to take possession of the personal dimension we overemphasize the mysteries of "creativity" at the expense of rationality and the critical power of well-ordered argument; if the social aspects are handed over to the sociologists, we get a description of research as an N-person game, with prestige points for stakes and priority claims as trumps. The problem has been to discover a unifying principle for science in all its aspects. The recognition that scientific knowledge must be public and *consensible* (to coin a necessary word) allows one to trace out the complex inner relationships between its various facets. Before one can distinguish and discuss separately the philosophical, psychological, or sociological dimensions of science, one must somehow have succeeded in characterizing it as a whole.[2]

In an ordinary work of science one does well not to dwell too long on the hypothesis that is being tested, trying to define and describe it in advance of reporting the results of the experiments or calculations that are supposed to verify or negate it. The results themselves indicate the nature of the hypothesis, its scope and limitations. The present essay is organized in the same manner. Having sketched a point of view in this chapter, I propose to turn the discussion to a number of particular topics that I think can be better understood when seen from this new angle. To give a semblance of order to the argument, the various subjects have been arranged according to whether they are primarily *intellectual*—as, for example, some attempt to discriminate between scientific and nonscientific disciplines; *psychological*—e.g., the role of education, the significance of scientific creativity; *sociological*—the structure of the scientific community and the institutions by which it maintains scientific standards and procedures. Beyond this classification, the succession of topics is likely to be pretty haphazard; or, as the good lady said, "How do I know what I think until I have heard what I have to say?". . .

Notes

1. This point I owe to Professor Kömer.

2. "Hence a true philosophy of science must be a philosophy of scientists and laboratories as well as one of waves, particles, and symbols." Patrick Meredith in *Instruments of Communication*, p. 40.