SCIENCE AND REALITY

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SCIENTISTS themselves, and even those buck privates who form the rear of the scientific profession, are alternately praised or blamed for being materialists. At best it is said they deal with stark reality, they get down to basic things, and definitely make contact with the fundamental, material stuffs composing the universe about us. Many people, fretful because they feel somehow detached from reality—often they are economists or sociologists—will congratulate workers in physical and biological sciences because they truly know reality.

That attitude is so often expressed that one begins to wonder and wondering, it seems best to consult some of our greatest scientists to discover how they felt about reality. What is the opinion of such men as Einstein and Heisenberg on this matter? Then, returning to the sturdy routine workers who perform the humdrum jobs in research laboratories without which great discoveries could never occur, what is the experience of lowlier laboratory workers? What is real under the microscope? What is real out there in the sky?

Here is a scientific article on star counting. It is illustrated by photographs. One series of photographs depicts the same patch of sky as seen using telescopes of increasing power. The first picture represents what can be seen with a lens that renders only stars of the twelfth magnitude clearly visible. The second, third, and fourth pictures show the enormously increasing number of stars that appear to exist when stronger glasses bring stars of the fifteenth, eighteenth, and twentieth magnitude to visibility.

The ancients saw the stars with the naked eye. In that way one can count about six thousand of them and one then sees stars of only the first to sixth magnitudes. Stars of the first magnitude are a hundred million times brighter than those of the sixth magnitude. It is practically impossible to count all the stars in the sky as seen by our most powerful telescopes; they run into hundreds of millions. Therefore, counts are made in restricted areas of the sky, and these are assumed representative of the whole.

All right then: What is the reality here—the few thousand stars seen by the naked eye or the countless millions seen by the aided eye? Or is the true reality what might be seen through a glass of infinite power that would bring in all the stars? Or is it the actual conditions there millions of light years out in space, conditions we can never experience in the sense that we experience things that happen in the same room or on the same earth with us?

We may leave the sky and consider a razor blade. We marvel at its smooth edge. It feels and it looks smooth. We examine it under the microscope and it is rough and jagged. What is the reality about it?

Here is some salt on the table. We use it to season food. We can get all we want very cheaply and it means little to us, but we read that salt is rare and difficult to obtain in certain parts of the world and is there esteemed highly as a great delicacy. What is the reality about this common salt?

A chemist takes it to his laboratory. By appropriate means he breaks it down. He shows us a soft, bright metal that can be cut with a penknife and which, when thrown on water, spontaneously bursts into flames. He shows us a queer greenish gas which makes us cough if we try to breathe it. He says the metal is sodium and the gas chlorine and that the common table salt is really composed of them.

Is it really, we ask? What trace of that soft explosive metal and that green gas is there to be found in this white powder, common table salt? If sodium and chlorine exist in the salt it is obvious they must reside there as their own proper selves, at least that is the only way we could recognize them. The chemist says that common salt ($NaCl$) equals sodium (Na) plus chlorine (Cl). What does he mean by equals?

Turn to another problem, that of lead in food. Lead is a poison. If quantities of it remain in fresh fruits and vegetables after they have been sprayed to rid them of insects the foods may be toxic to human beings. Yet certain small traces of lead are not toxic; poison experts are agreed that the body can throw these off without damage. Also certain foods contain no lead—at least that is the report in a certain year.

A year or two passes and it is now reported that practically every food contains some minute trace of lead. None are exempt. What has happened? A new and more refined method of chemically determining lead has been invented. Foods that appeared to contain no lead when the old method was used can now be shown to contain it by this new and very delicate method. What is reality then? Isn't it a function of the current refinement of instruments and methods? What else?

Laboratory experience is often disconcerting and humbling. Any number of times I have thought I had really proved what had not been proved at all. Any number of times I have truly "seen" certain experiments turn out as my preconceptions told me they should turn out when improvement in methods or better instruments, or a chance inexplicable test which changed my preconception, soon made me "see" the reverse quite as plainly.

At one time I worked for some years upon what I sincerely supposed to be one compound in the blood which proved later to be quite another. What happened later was still more striking. The man who originally discovered the second compound, and who had also reported synthesizing, or building it up, from its simpler constituents, was wrong about its constitution. In the end it was discovered that three different biological chemists in three different countries had been working for some years in the effort to make a nonexistent substance!

Certainly the reality that the scientists apprehend differs from that the ordinary run of us experience simply because he uses different methods and instruments, as well as a different background of knowledge, in analyzing and examining the data of experience. What the scientist regards as real today depends upon the state of his knowledge, the refinement of his instruments, and the perfection of his methods. Change any of these factors and he will of necessity announce a new reality tomorrow.

Moreover the scientist, like other human beings, is animated by certain desires. For instance he prefers a monistic to a dualistic universe. He prefers a certain continuity in the phenomena of nature. He does not like to countenance arbitrary breaks in natural phenomena and often says nature makes no sudden leaps. He assumes that objects in some way persist and maintain their identity, though he can not prove this.

What is the identity of a glass of water? The water depends for its shape and contour upon the nature of the glass. But what is more, its molecules are assumed to be in a state of perpetual motion at tremendous speeds. At the top certain molecules are continually shot off into space and become water vapor. Hence the glass of water does not persist as such from one second to the next though the scientist has to assume that it does.

The scientist also expects to find a certain simplicity and economy in the explanation of natural events, and he holds that the simplest and most economical explanatoin is therefore the truest—a piece of pure metaphysics. He tried to build such systems as will predict future consequences accurately and he requires some sort of "stuff"—atoms or what you will—with which to build. He holds to the theories of the uniformity of nature, the existence of determinism in nature, and the validity of inductive generalization.

Like the rest of us, the scientist feels that when his expectations have been fulfilled he is on the right path, and there is comfort in that. At one time the universe made up of hard little billard-ball atoms seemed to fulfill these expectations, along with the fiction of potential energy—precisely enough fictioned potential energy being created to enable the system to preserve its total energy and thus satisfy the so-called law of the conservation of energy. But those things have passed away. They are no longer real.

Atoms were invented to explain certain things scientists observed in their laboratories, but they eventually assumed a suppositious reality and in some mysterious way seemed to become more real than the facts they were invented to explain. The same holds for our more modern electrons, protons, and other particles, as well as for genes and cells in biology. These things are constructs, not realities, yet leading scientists often appear to feel as if they were very real.

However, it is said that the scientist "verifies" his assumptions. What does this consist in? The scientist determines whether the consequences deduced from his hypothesis are or are not contradicted by his observations of nature. If the hypothesis can not be verified it is excluded ruthlessly, for science is interested not in truth as a whole but only in technically verified truths.

The only facts that have standing in science as it is are those that fit into its current pattern of truth. The hypotheses of science are indeed verified by the facts observed, but it must be remembered that the only facts considered valid to verify the hypothesis are those not too obviously in conflict therewith. Hence scientific laws and the facts of nature form a mutual verification society.

Upon what do the judgments of science depend? Upon a mere half dozen factors. There are first, judgments of perception such as: The rabbit is white. Second, there is the belief in the existence of an external world, fundamental but incapable of proof. Third, there is the belief in the trustworthiness of memory, and we all know how little reliance can be placed here. Fourth, there is the belief in the existence of other selves which are, by and large, like ourselves, also fundamental but incapable of proof. Fifth, there are such self-evident analytical judgments as one foot equals twelve inches, axioms agreed upon by definition but having nothing whatever to do with the events of nature or with what ordinary people regard as reality. Sixth, and last, there are synthetic propositions concerning the relations between universals—such as black is different from white. Upon these factors the whole fabric of science rests.

As a result all science becomes a highly personal and subjective affair. It used to be said that the social sciences were not truly scientific because the investigator could not be objective; he himself formed part of his object of study. This is now seen to be true of the biological and physical sciences as well. It is true to such an extent that in *Science Progress* for October 1932 Prof. G. B. Brown produced two or three pages of delightful humor on the subject—for the elect and initiated.

Herein he depicted such great scientists as Einstein, Sir J. J. Thompson, Lord Rutherford, Sir Arthur Eddington, Dirac, and Heisenberg as each building his own peculiar little structure of highly personal physics. Some, like Schrödinger and de Broglie, were represented as living in rows of huts. Einstein was described as standing at the entrance to a cave and facing a cliff of solid rock, a little undecided just what to do.

Then, what is the opinion of such a man about reality? That should be more important than almost anything else. I sought to find out, and in his Herbert Spencer Lecture "On the Method of Theoretical Physics," delivered at Oxford University June 10, 1933, Einstein delivered himself of his opinion. The lecture started with the thought just mentioned above, subjectivity in physical science. For Einstein began by saying that a man's "view of the past and present history of his subject is likely to be unduly influenced by what he expects from the future and what he is trying to realize today." Our own Prof. P. W. Bridgman expressed a similar idea some years ago when he wrote that "the chances are, therefore, that the relations between phenomena will be found by those who are previously convinced that the relations exist."

This idea that the beliefs of the physical scientist determine the kind of science he develops is not new. In the last article of the late Viscount Haldane published in this country, in 1928, he declared that all science had been driven back upon mind as the only basis upon which explanations were available. In discussing "Reality in Physics" before the American Physical Society, late in 1931, Dr. W. F. G. Swann described reality as "the most alluring of courtesans, for she makes herself what you would have her at the moment."

In his address delivered as President of the British Association for the Advancement of Science in 1934 Sir James H. Jeans said that "in the old physics the perceiving mind was a spectator; in the new it is an actor. Nature no longer forms a closed system detached from the perceiving mind; the perceiver and the perceived are interacting parts of a single system." We may accept it as fundamental in modern scientific thought that the mind determines the type of reality the physical or other scientists claim to perceive.

Einstein, in the address we were following, continued that pure logical thinking could give us no knowledge whatever of the world of experience, conclusions reached by such processes being entirely empty so far as reality is concerned. However, modern theoretical physics consists of certain basic concepts, which are purely invented fictions, related together logically by laws, from which certain consequences are deduced logically. The experiences and observations of the scientist must conform to these theoretically deduced consequences, otherwise the system is faulty.

Reason supplies the structure of modern science and experience produces the data. Science differs from a geometry like Euclid's in that Euclid made no direct attempt to relate the consequences of his logical theory to the experiences of reality. Hence, in modern science, a fact is worth nothing until it is sustained by a good theory, but the whole structure is, Einstein says, founded on "certain basic concepts and laws which are not logically further deducible." These indispensable concepts are merely assumed "true" as were the axioms in our school geometries.

Therefore, unproven assumptions underlie all science and the character of any science depends largely upon the character of the assumptions regarded as true in the first place. In the eighteenth and nineteenth century, however, scientists did not realize the purely fictitious character of their basic principles. Newton, for instance, believed that he developed his basic principles about space, time, mass, force, acceleration, etc. directly from experience.

While Newton was rendered a bit uneasy by his idea of absolute space (because it involved the idea of absolute rest and he could find no body at absolute rest) he did not suppose his basic concepts to be "free inventions of the human mind," as Einstein puts it. Einstein and his coworkers, however, accepted the idea that the basic postulates were freely invented and declared that "the fictitious character of the principles is made quite obvious by the fact that it is possible to exhibit two essentially different bases, each of which in its consequences leads to a large measure of agreement with experience."

It is well, of course, for science to diminish the number and increase the simplicity of its basic concepts, but there is then an ever-widening gap between the axioms and the consequences. The widening of that gap worries modern physicists a great deal, Einstein admits. Then, he asks, has a scientist any reason to hope that they will find what he calls "the correct way" in time. His answer to his own question is:

"To this I answer with complete assurance that in my opinion there is *the* (his own italics) correct path and, moreover, that it is in our power to find it. Our experience up to date justifies us in feeling sure that in Nature is actualized the ideal of mathematical simplicity. It is my conviction that pure mathematical construction enabled us to discover the concepts and laws connecting them which give us the key to the understanding of the phenomena of Nature."

That is all. We may achieve understanding, but never direct knowledge of some one absolute reality. Experience must still guide us in the choice of the mathematical concepts to be used, though it must not be the source of their derivation. "The truly creative principle resides in mathematics." Moreover Einstein is a strong believer in simplicity in Nature, a belief which, we must remember, determines the character of the science he will evolve and espouse. He demands that science at all times search "for the mathematically simplest concepts and connexions of them" and in the very paucity of the possible concepts and relations he sees "justification for the theorist's hope that he may comprehend reality in its depths."

None the less the reality so comprehended and expressed in formidable equations would differ enormously from what the average person regards as reality. The detailed picture of space and time made familiar to us by the older physicists would vanish utterly. Instead we should have a group of impressive mathematical formulae which can not be pictured. These new concepts can not be reduced to the old terms nor visualized by use of the old pictures of reality.

The theory that mathematics will ultimately explain the universe is a metaphysical theory, of course, though it is the very heart of modern scientific explanations. Ultimate reality and causal efficacy are ascribed to mathematics, and this world is then identified as best it may be with the realm of material bodies moving in what we naively call space and time. This Einsteinian world is not one of stuffs or substances possessing certain qualities experienced by human beings. It is a world of purely mathematical electrons which move in accord with fixed mathematical laws. Is this reality?

Here is an ethereal stratosphere of four-dimensional continuums, Riemannian metrics, vector-fields, anti-symmetrical tensor-vector-fields, and spinor field quantities. All of this is very remote from our daily life. Even quite expert scientists may become somewhat awed by this hypnotic nomenclature. Yet the results obtained mathematically depend for their validity upon the number and quantity of the data available, or upon the number of observations that happen to have been made at the time the predicting calculations were carried on.

For instance, both Neptune and the trans-Neptunian planet were found as predicted simply because the limited number of inaccurate observations used by Leverrier and Lowell in their calculations happened by the merest chance to give a result that was later verified. Had either prophet had more reliable data, or had the observations existed in greater number, their predictions would have been completely falsified. So it is through all mathematics.

When a scientist weighs a crucible on his balance, takes a reading on a colorimeter or polariscope, measures electric current by observing a pointer—and practically all science consists merely in observing pointer readings—he must finally arrive at a figure he calls "correct." That is the average of a series of five, ten, or twenty weighings or readings. It very often is not precisely the same figure as that for any one real weighing or reading, yet this purely mathematical average is announced as the correct value.

Then what is the reality the scientist discovers? It depends not only upon his original choice of basic concepts and his personal beliefs, but also upon the quantity of data at hand. It is manifestly certain that a chemist will not get exactly the same value when he weighs a crucible five times and averages these weighings as when he weighs it twenty-five times and averages those weighings. It is just as obvious that a rather unusually erroneous weighing will bulk more heavily in the first average than in the second.

Hence mathematics is treacherous. It can not give us the inner nature of real reality. It gives us a sort of austere mathematical reality—a reality of averages, equations, and abstract concepts. This is, however, the present chosen reality of modern physics and of physical science generally. It fixes the pattern of science and, as we saw earlier, that pattern determines the facts science will accept, just as it is determined by the facts science has accepted.

For instance, it happens to be true that every major observation of the speed of light that has been made since 1902 has given a slightly smaller result than the previous observation. It would seem logical to conclude, therefore, that the speed of light in miles per second is really diminishing, but the scientists conclude no such thing. The pattern of modern physics demands that the speed of light remain absolutely fixed, hence irregularities are attributed to "experimental error."

Charles Peirce, noted American scientist and philosopher, went so far as to suggest accepting the actual results in the case of any scientific experiment, rather than having resort to averages. He was bothered by the scientist's pet alibi, "experimental error," and said why not assume that the individual results are correct and that all scientific findings forever oscillate around purely theoretical and fictioned fixed points? His heretical suggestion has been largely ignored by science.

Consequently science continues to accept as "real" that which its current pattern regards as real, no more no less. The chemist accepts as the result of his analysis the average of twenty weighings on his refined balance, not the result—the actual, true, real, experimental result, that is—of a single weighing. Physical reality is reduced to a set of equations, the electrons themselves have become disembodied ghosts or near wave forms in four-dimensional space-time, and statistical averages rule dictatorially over all.

Speaking in Germany in the fall of 1934 Prof. W. Heisenberg, noted physicist and discoverer of the so-called principle of indeterminacy, remarked that the old physics which dealt with the behavior of real entities in space and their real variations with time was no more. The old view that "the occurrence of events in time and space is independent of observation" is gone forever. The concepts of absolute time and of determinacy have no place in the new cosmic physics, however useful they still are in certain limited fields such as mechanics, optics, or thermo-dynamics, where they remain as unaltered as did the geography of the Mediterranean Basin after the voyages of Columbus and Magellan.

Heinsenberg very plainly said: "Thus Nature influences modern natural science more than the earlier form in such a way as to place the old question of realization of reality upon a new basis and to answer it in a new manner. Previously the pattern of exact science led to a philosophical system in which a definite truth—perhaps the 'Cogito, ergo sum,' of Descartes—was the starting point from which all problems of world-view were to be attacked. Nature in modern physics has reminded us clearly, however, that we may not hope to reach the entire region of the understandable from such a fixed basis of operation."

If any science should give us what we formerly regarded as reality it should be physics. But what have we found? Physics is a system of symbolic construction. It starts with definite facts that can be perceived but which are too gross for its immediate acceptance. Its pattern will not admit these crude data. So it proceeds next to work in a highly theoretical field where many things are imperceptible and where there is great freedom from the restraints of experience. Thereafter it returns to the facts of nature to check up.

A physicist sees, for instance, the deflections of a pointer on an ammeter and notes that these change in certain ways when he adds more wire to the electrical circuit. He then retires to his chamber of speculations and invents entities he has never observed in order to explain these facts, *i.e.*, to make them intelligible to him in terms of his thought pattern, for he believes he has perceived similar things in similar but really quite different connections.

He calls these invented entities "electric current," "resistance," "electromotive force," though he admits their properties are merely assumed by definition, and they are useful merely because of their symbolic character, and of the relations into which they can enter. He derives a law, such as Ohm's Law, which no real electric current ever does follow exactly. He deduces certain consequences that should occur if this law were approximately true, then he returns to the world of experience to see what he can see.

If the law is not verified it is false, though if it is verified that does not prove it true—it proves merely that it held true in the particular tests made. In making these tests, the physicist says he is measuring current, resistance, and electromotive force. He makes his fiction of the electric current still more definite by imagining streams of fictioned particles going through wires like molecules of water down between river banks, and he calls these particles electrons.

He next thinks of these particles as being charged with electricity and, finally, of producing effects (like cloud tracks) which can be detected by the eye. Yet the electrons are never objects of perception. They are not part of nature, though by using such concepts the physicist can make correct statements about matters of fact that can be perceived in nature. The whole field of symbolic construction of physics is thus filled with masses, forces, electrons, and so forth, but the reality we are searching does not appear.

It never does appear anywhere in science where materialism is outmoded. For science and what the average person regards as reality have parted company, and it looks as if the divorce were absolute and final.