confluence that constrains their respective values.

In the history of physics, when three or four independent experimental procedures achieve the same result, with none opposing, that result is considered to be a fact. Such confluent relations are then fundamental and permanent; despite nature's being a participatory book, they are the precise points in which objectivity and truth enter into physics.

References

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2. N. Bohr, *Atomic Physics and Human Knowledge,* Wiley, New York (1958).
3. For further discussion, see J. A. Wheeler, *At Home in the Universe*, American Institute of Physics, New York (1992).

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Arthur Eddington, in his book *The Philosophy of Physical Science* (U. of Michigan Press, 1958), posed the question whether Ernest Rutherford had found or manufactured the atomic nucleus. If he were still alive, I suspect Eddington would be asking a similar question about quarks. The kind of approach to physics that concerns Michael Riordan was alive and well before World War II and was not without its critics then.

Herbert Dingle, philosopher and historian of science, wrote a *Nature* article entitled "Modern Aristotelianism,"[1] in which he attacked the ideas of P. A. M. Dirac, Eddington, and E. Arthur Milne, for many of the same reasons as Riordan attacks what he calls Platonic physics. Dingle's article provoked many responses.[2] Omitting the three from the people criticized, the replies were roughly equally divided for and against Dingle's point of view. Eddington's belief that dimensionless ratios of the constants of nature could be deduced by pure reason was, of course, part of Dingle's target. That belief is sometimes thought of as the preoccupation of Eddington's old age, but in 1937 he was only in his fifties. And the correspondence is evidence that he was not alone in thinking along those lines, even if he did pursue the idea more single-mindedly than others did. Perhaps this alternative kind of science will be ever with us.

References

1. H. Dingle, *Nature* **139**, 784 (1937).
2. See ref. 1, pp. 997 and 1025.

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Michael Riordan appropriately concludes his Opinion piece by quoting Galileo: "Philosophy is written in this great book, the Universe, which stands continually open to our gaze." But, perhaps to maintain his antitheoretical tone, Riordan withholds from us Galileo's next, and I think crucial, sentences: "But one cannot understand this book if one did not learn how to understand the language, and does not know the characters in which it is written. It is written in the language of mathematics. . . . Without [mathematical concepts] it is impossible for us to understand a single word of it."

Few sane people would quarrel with Riordan's main point that the essential criterion for a theory's acceptability is that it have predictive power. That means, first, that it should be experimentally verifiable or contradictable, and second, that it should encompass phenomena or events that are extensions of ones already encompassed. Riordan overlooks the second point.

Surely, though, predictive power is not the only acceptability criterion. A good theory must also be systematic, comprehensible, attractive—even beautiful. Although it would be disastrous if, as Riordan fears, some people suggested that "mathematical beauty, naturalness, or rigidity . . . should suffice," an equally grave error would be to discard such properties in assessing the acceptability of a theory. We are well advised to listen to Albert Einstein, who said, "A theory is acceptable to us only if it is beautiful." And P. A. M. Dirac added, "Einstein introduced the view that something that is beautiful mathematically is bound to be correct physically. The proof [of a complex theory] comes not really from experiments. The real foundations come from the beauty of the theory. . . . It is the essential beauty of the theory which, I feel, makes us believe in it." Henri Poincaré said, "Science is useful because it is beautiful." Such statements may sound exaggerated, but science is not here only to discover isolated facts. It always was and should remain an inspiration to and enrichment of the human spirit and a means to discover the overall structure of events, not just facts, as Eugene Wigner emphasized.

An interesting example of how criteria other than experimental verification are also essential for scientific progress is the following: Often it happens that one has a fine theory, but that new observations or experiments reveal phenomena that cannot be encompassed by the relevant established theory. One then tries to accommodate new "facts" by adding extraneous elements to the beautiful theory. But such patching up, although successful, makes the entire edifice ugly. More often than not, that ugliness is a sign that the underlying theory is incorrect. A completely new conceptual beginning becomes necessary, and eventually, a new beautiful theory will emerge—to be tested by utterly new suggested experiments. This example also illustrates well the interplay between experiment and theory, which Riordan seems to see rather one-sidedly. He suggests, perhaps unwittingly, that the main role of experiments is to disprove erroneous theories.

Murray Gell-Mann was certainly right when he insisted that his quarks are just mathematical entities. After all, his SU(3) *flavor* quarks (with only three flavors, nota bene) and broken symmetry have very little to do with the physical, unbroken SU(3) *color* quark symmetry. The quark picture of matter became possible only after Y. Nambu and others came to the idea of color as a purely theoretical consideration to reconcile the possible quark picture with the spin-statistic theorem. Even that was not enough to accept quarks as physically real. The entirely theoretical edifice of renormalizable quantum chromodynamical field theory had to be developed first. Riordan disregards those facts in the discovery of quarks and overemphasizes the role of the beautiful deep inelastic scattering experiments. These experimental results indeed led Richard Feynman to the idea of pointlike entities inside nucleons; but partons are not quarks.

Finally, I can't see how the unexpected experimental discovery in 1974 of the J/ψ meson was, as Riordan put it, "Nature's slap in the face, which finally made physicists sit up and admit that quarks truly existed." That discovery merely showed that there is at least one more flavor than in the Gell-Mann–Zweig scheme, so that instead of the SU(3) flavor group, perhaps an