as the pathway to truth."

Among scientists, this formulation of scientific endeavor is widely held and seems so self-evident that people who disagree with it are perceived as irrational or oppositional. But is the distinction between the knowledge structures of science and nonscience really that clear-cut?

Clearly, science can make one particular claim: It works. Unlike any other form of knowledge, science provides a means of constructing machines and theories that are unequaled in their ability to predict and provide control. Our modern technological society is a monument to its success. Science also has created an intricate structure of knowledge to provide coherent and self-consistent explanations of a wide range of phenomena.

But while this success is incontrovertible, it may well obscure the subtleties of science's knowledge structure. Consequently, we may construct a model of scientific knowledge and evolution that makes science seem more different from other forms of knowledge than may actually be the case.

Philosophers and science historians such as Thomas Kuhn and Imre Lakatos[1] have wondered why science works so well. They have looked at its structure, its evolution, and the mechanisms by which scientific theories have progressed. Their analyses and conclusions will be unsettling to many scientists. They find that experiment and theory are not distinct categories, so that when one compares experimental data with theory, one is not really testing a theory by comparing it with nature. Instead, one is making a choice among competing theories, and no set of objective rules governs such a choice. The scientific community arrives at its theories in ways that are not entirely objective. No clear line of demarcation exists between experiment-based knowledge systems and belief-based ones. Some philosophers of science have even argued that the demarcation problem—that is, defining science so that it can be distinguished from religion—is inherently insoluble.

Scientists can ignore or summarily reject these conclusions by saying that we know that scientific knowledge is objectively obtained even if we cannot articulate exactly how we know this. But just as Mouroulis accords his "cosmology colleagues the same respect and skepticism that he expects from them," we should extend this courtesy to the philosophers and historians of science. Their works are scholarly, peer-reviewed, and critiqued by their colleagues. And these philosophers are admirers and supporters of science, not opponents. We at least owe it to them to study and understand their views. Otherwise we will be doing what we often criticize nonscientists for doing: rejecting counterintuitive ideas (such as wave–particle duality or time dilation) because they are "obviously" untrue.

One other aspect of this discussion puzzles me. The scientific community takes young-Earth creationists to task for holding irrational views but tends to ignore the views of mainstream religions, when the differences seem to be matters of degree and not of principle. Any theistic religion typically asserts the existence of at least one scientifically inexplicable supernatural event. Should scientists reject all such claims?

The committed naturalist would argue that we should, otherwise the entire framework of science will collapse. Science starts with the assumption that all natural phenomena are explainable by natural laws that can be discovered using the methods of science. No deviation from these laws is allowed. Miracles, which by definition are direct contradictions of the workings of natural laws, presumably have no place in this framework. Evolutionary geneticist Richard C. Lewontin[2] says it plainly: "We cannot live simultaneously in a world of natural causation and of miracles, for if one miracle can occur, there is no limit." His point is well taken. If the scientific community concedes even one miraculous event, then how can it credibly contest the young-Earth creationist view that the world (and all its fossilized relics) was created in one instant just 6000 years ago? So if we reject creationist views on this basis, should we also reject any supernatural claim from *any* religion?

These are thorny and nontrivial issues, which need the kind of extended discussion that I have provided elsewhere.[3] But for the present, I can only echo letter writer Philip E. Kaldon, who sums it up beautifully:

> It is easy to say that we physics teachers do not teach "belief" because we are teaching science. It is not so clear-cut to the students—and sometimes those of us teaching. And at the end of the day... I am grateful to those who have spent the time to think about what they are being asked to think about, no matter their personal conclusions.

References

1. T. Kuhn, *The Structure of Scientific Revolutions,* U. of Chicago Press, Chicago (1970). I. Lakatos, *The Methodology of Scientific Research Programmes,* Cambridge U. Press, New York (1978).
2. R. C. Lewontin, *Scientists Confront Creationism,* L. R. Godfrey, ed., W. W. Norton, New York (1983).
3. M. Singham, Phi Delta Kappan, **81** (6), 424. M. Singham, *The Quest for Truth: Scientific Progress and Religious Beliefs,* Phi Delta Kappa Educational Foundation, Bloomington, Ind. (in press).

MANO SINGHAM
(mxs24@po.cwru.edu)
Case Western Reserve University
Cleveland, Ohio

Background Highlights in X-Ray Imaging

In connection with the article entitled "Phase-Sensitive X-Ray Imaging" in the July issue of PHYSICS TODAY (page 23), I would like to add a little more background to two aspects of the topics covered. First, in the context of crystal-based methods of phase-sensitive imaging, the early work of Eckhart Forster, Konrad Goetz, and Peter Zaumseil[1] is worthy of mention because it was apparently the first example of a deliberate double-crystal approach to phase-contrast imaging (which they called "Schlieren topography"), and precedes the phase-dispersion introscopy (PDI), or diffraction-enhanced imaging (DEI), approach referred to in the article. The work of Forster, Goetz, and Zaumseil described x-ray investigations of laser fusion targets by a double-crystal method and contained a wave-optical explanation of the observations. I believe the existence of this paper only became known to the authors of papers cited in the article after their papers had been published.

Second, regarding phase-contrast radiography, phase retrieval from intensity data is currently a lively area of research, providing a noninterferometric means for quantitative phase determination that bypasses the usual 2π ambiguity encountered in the interferometric approach. The noninterferometric approach relies on the mathematical

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or numerical inversion of the scattering problem for intensity data measured, for example, in the Fresnel or near-field regime for phase-contrast radiography. In this regard, the synchrotron-based work of Keith Nugent and colleagues at Melbourne University in Australia provides an elegant demonstration for a pure phase object.[2]

References

1. E. Forster, K. Goetz, P. Zaumseil, Krist. Tech. **15**, 937 (1980).
2. See, for example, K. A. Nugent *et al.*, Phys. Rev. Lett. **77**, 2961 (1996).

STEPHEN WILKINS
(wilkins@cmst.csiro.au)
Commonwealth Scientific and Industrial Research Organization
Clayton, Victoria, Australia

Quark 'Color' Clarified

I would like to correct any possible misunderstanding regarding quark "color" that I may have conveyed in my review of Helge Kragh's book *Quantum Generations* (PHYSICS TODAY, May, page 56). O. W. Greenberg's order-three parastatistics (a generalization of Fermi statistics)[1] and Yoichiro Nambu's SU(3)″ group,[2] now called the "color" group, give identical results in the group-theoretical characterization of quark states. The important additional step taken by Nambu was to introduce an octet of gauge fields (now called color gluons) coupled to the color charge. Nambu's SU(3)″ is a local gauge symmetry that is the basis of quantum chromodynamics. I thank Greenberg for calling my attention to a possible misreading of the distinction I was drawing between color as a quantum number and color as a gauge symmetry.

References

1. O. W. Greenberg, Phys. Rev. Lett. **13**, 598 (1964).
2. Y. Nambu, in *Preludes in Theoretical Physics*, A. De-Shalit, H. Feshbach, L. van Hove, eds., North Holland, Amsterdam (1966).

LAURIE M. BROWN
Northwestern University
Evanston, Illinois

Learning to Control Quantum Systems

We enjoyed the article in Search and Discovery (PHYSICS TODAY, September, page 24) on our recent work applying coherent control of quantum systems to the topic of x-ray generation. The article does an excellent job of covering recent experimental work in this area. However, we feel it is important to acknowledge that this experimental work was motivated by the suggestions of Herschel Rabitz of Princeton University. Rabitz first proposed, by demonstrating in theoretical simulations, that "learning control" of quantum systems could be applied both to achieve a desired outcome,[1] and as a "probe" to learn more about the system being studied.[2] These early works provided strong motivation for the experimenters to persevere in what we expect to be an exciting new field of "engineered" quantum dynamics. This is also a beautiful example of a case in which engineering concepts, when adapted appropriately, can have fundamental impact in basic physics and chemistry.

References

1. R. Judson, H. Rabitz, Phys. Rev. Lett. **68**, 1500 (1992).
2. H. Rabitz, Adv. Chem. Phys. **101**, 315 (1997).

HENRY C. KAPTEYN
(kapteyn@jila.colorado.edu)
MARGARET M. MURNANE
(murnane@jila.colorado.edu)
JILA, University of Colorado
Boulder

Correction

July, page 23—Ulrich Bonse and his colleagues at the University of Dortmund (Germany) and at the Hamburg Synchrotron Radiation Laboratory at the German Electron Synchrotron (DESY) are also investigating the use of phase-contrast x-ray interferometry for clinical and medical applications.[1] In particular, they have demonstrated the potential of three-dimensional phase-contrast x-ray microtomography using synchrotron radiation. With this technique they have mapped the mass density of nerve and brain tissues in intercranial rat specimens. The experimenters observe a sharp delineation between the two types of tissue as well as clear patterns of nerve fibers. They also see increases in mass density that could identify initial stages of tumor growth.[1]

1. U. Bonse, F. Busch, Prog. Biophys. Molec. Biol. 65, 133 (1996).
2. F. Beckmann *et al.*, Biophys. J. 76, 98 (1999).