Cathedrals and other edifices

Leo P. Kadanoff

One argument often used to justify society's support of pure science is that contemporary science is producing great and enduring structures that will be passed on to future generations as a major portion of the legacy of our age. The analogy to medieval cathedral building is frequently pressed. In this column, I point to a few of the results of physics that are likely to endure and remain important, not to just a few specialists in physical law, but to people in general.

One lasting product is the grand idea that the entire universe is governed by a few simple laws and that these laws are within human understanding. One beginning for this point of view is the Newtonian insight that apples and moons obey the very same laws of force and acceleration. This start has led to our major effort to derive the most fundamental laws that govern all parts of the observable universe. Bit by bit, we have seen the unification of electricity and magnetism, of space and time, of quantum theory and electromagnetism, of these and the weak interactions, and now perhaps of all known forces via the proposed string theories. These advances have been paralleled by deeper insights into atomic physics and condensed-matter problems, into chemistry, biology and molecular biology (made in part by people trained in physics)—insights that have gradually led us to the view that every portion of the world can be understood as a manifestation of a small group of rationally comprehensible laws. Perhaps the pinnacle of that view is our gradually emerging understanding that living creatures, including even ourselves, are indeed ordinary parts of the natural world.

Another part of the grand structure is the opposite view—that natural laws are diverse. Different laws may apply at different levels of organization, partially because the objects studied at the various levels are not the same (see PHYSICS TODAY, September, page 7). Our own gross motions are described by classical mechanics; those of our blood, by hydrodynamics; the details of our hemoglobin (compared with that of other species), by the laws of genetics; the binding of oxygen with the hemoglobin, by quantum laws. One can even have situations in which laws at the different levels are in apparent contradiction: Microscopic laws of nature imply time-reversal invariance. This is roughly the statement that movies run backwards "look right." But thermodynamics says just the opposite. Our own perceptions fall within the thermodynamic world. Thus we see at each level of scale and organization within the world different rules, different generalizations, different natural laws.

Edward Purcell has produced a fine example of this "many worlds" view of nature by asking the question "What is the physics a bacterium needs to know?" The answer is that the bacterium lives in a high-viscosity world, with laws very different from those in a human-scale, low-viscosity situation. Another and perhaps even more striking example is the contrast between the quantum world and the classical one as revealed in the Einstein–Podolsky–Rosen *gedanken* experiment and John S. Bell's analysis of the classical interpretation of that experiment. In discussing this example, David Mermin has pointed out (PHYSICS TODAY, April 1985, page 38) that in a quantum world our ideas of logic and causation do not work out quite the way we might expect. And worse(?!) yet, the quantum world may impinge upon our own, leading to results that challenge our intuitive view of connection and causation.

Physics has enriched the discussion of many other topics that should interest any thinking individual. Consider time. Any person might wish to know the relation between the time we perceive and time as it "really is," and to do so that person might wish to think about the impossibility of communication across the light cone and the resulting loss of contact with regions inside black holes, and about the twin paradox (in which aging of different individuals depends upon the history of their motions), and about the Big Bang and the large-scale structure of space–time.

One more fundamental achievement of science is the prediction and control of the world around us. It is very pleasing to be able to answer such questions as why the sky is blue, why diamonds are hard and why snowflakes are so diverse. (We cannot fully answer the last one yet.) But predictability in natural situations should be more than just casually pleasing to us. This predictability demonstrates that the physical laws for the objects that surround us are within our grasp. From understanding can arise control. It is satisfying to see science and the engineering art working in concert to produce such useful advances as medical x rays, solid-state electronics and satellite communication.

The role of scientists in these types of engineering advances has changed considerably since the second world war. At that time there were very few engineers expressly trained in applying advanced technology, so physicists had to take much of the role now filled by engineers. No more. Now, most fields of technology have very highly trained applied people—some scientists, some engineers—who carry out the R&D process. The role of pure science is that of finding totally new phenomena and new areas where simple and elegant laws might apply. For example, physics and physicists are right now trying hard to ask what new laws might govern complex systems. It's very fashionable to ask what laws might apply to a large group of simple circuit elements, or a large group of neurons, or even a large number of molecules in random environments. Here we see

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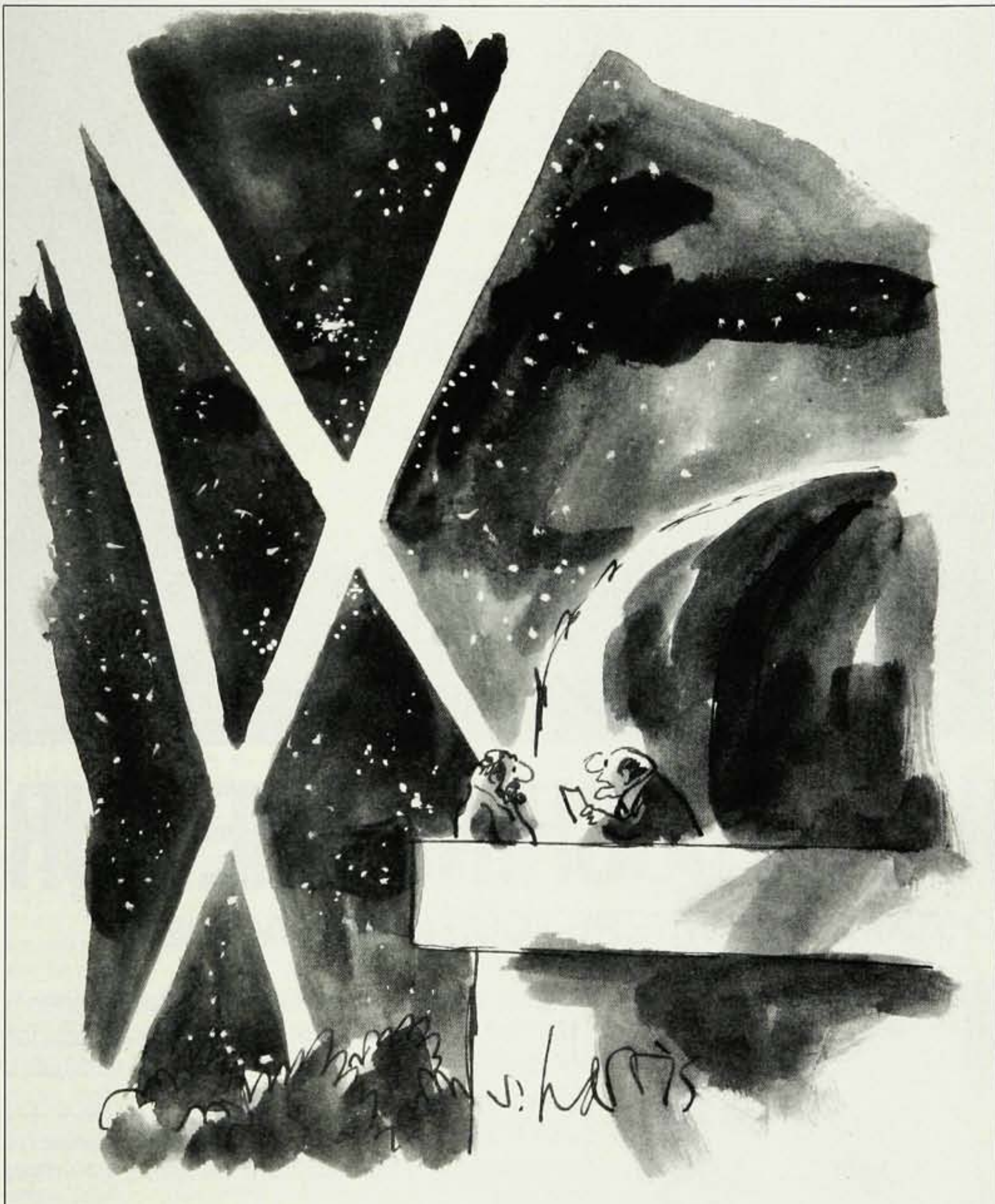
entirely new worlds to explore, but we recognize that the major problems in these areas have not yet been stated, much less solved. In another kind of advance, we are discovering that we can find or manufacture new systems that might yield exciting new generalizations. Manmade complex circuits, computer systems and complex (for example, layered) materials are new arenas for the application of scientific ideas. Even humble rocks have shown unexpected complexity, beauty and regularity. In studying these relatively new systems, we can expect new laws, new kinds of elegance and new beautiful science.

There's one more very important role that scientists can play in helping coordinate the research and design process. We scientists often have a reasonably reliable picture of what is feasible and what is impossible. For example, people cannot expect to communicate with their distant ancestors. A physical law stands in the way. One cannot achieve in any substantial measure the differential aging permitted by the twin paradox, because the accelerations required will be beyond our technology for the foreseeable future. For the same reason, we cannot expect any direct observation of strings. Scientists can and should point out these limitations about apparently feasible technology. Soviet agriculture and biology would have been saved many headaches had the government been willing to hear the voice of real science, rather than that of the party toady Trofim Lysenko. He made a career for himself by arguing that he could make advances in plant breeding via the inheritance of acquired characteristics, a goal that remained quite elusive. Here and today we are largely in a more favorable situation. Scientists can argue more effectively that there are limitations upon what technology can reliably achieve. We do not do extensive research in antigravity devices or faster-than-light communication because we have good reason for believing that these are impossible. We can also argue that some systems are too complex for effective control, given our present level of understanding. Thus, many scientists urge caution in activity related to the atmospheric release of fluorocarbons because we do not know the chemical and physical processes that relate these compounds to climate and to the level of uv radiation reaching the Earth. Ignorance of the processes involved and of the behavior of complex systems has effectively limited weather modification and has so far prevented reliable earthquake prediction. Earthquake modification seems only a distant dream. Similarly, many scientists have wondered whether any missile-defense system capable of protecting populations is feasible, given the weakness of our predictive powers for truly complex systems.

In our society, such questioning is considered a valuable activity. Scientific modes of thinking can be used to distinguish the correct from the incorrect and the practicable from the impractical. The possibility of making such distinctions is a kind of cathedral too. □



SIDNEY HARRIS

"THEY SAY THEY CAN'T UNDERSTAND WHY OUR LOOKING AT THE SAME OLD STARS SHOULD INTERFERE WITH A SHOPPING MALL PROMOTION."