AN EVOLVING PHYSICAL SYSTEM: THE STATE OF THE AMERICAN PHYSICAL SOCIETY

As APS approaches the end of its first century, its leadership faces some difficult choices about what new tasks the society should take on and how it should draw its boundaries.

Eugen Merzbacher

Among all the terms that we use casually in talking about physics, without feeling the need to define or explicate them, the winner of the Citation Derby is probably the word "system." Explicitly or by implication, the "physical system" defines the context in every class we teach, every seminar we give, every paper we write. Talking about physics without specifying the system is a vacuous exercise, and we exhort our students from the first day to think clearly about the system under consideration—what it includes and what it does not include, its relevant characteristics, its observable aspects, its degrees of freedom and its response to external influences and perturbations.

Every year The American Physical Society celebrates the unity of physics at its spring meeting by presenting, in conjunction with the American Association of Physics Teachers, a session of invited talks from several subfields in a form that appeals to a general audience of physicists. On Unity Day it is appropriate to reflect on the enormous range of physical systems with which we are concerned.

A serious examination of the concept of the physical system should begin with a historical analysis, starting in antiquity with those thinkers who first understood that the pronouncement of any physical law or regularity has to refer to a well-defined system. Instead, I will just make a few observations about the changes that have occurred in our notion of a physical system.

What do we mean when we speak of a system in physics? As our textbooks use the term, after centuries of refinement, it means something like this: A collection of particles, bodies, components or fields that can be described quantitatively by a number of variables and parameters and whose behavior, especially its time evolution, in relation to its external environment is subject to physical laws.

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That is a mouthful, and it is better to show a few examples. First and foremost, of course, we think of the solar system or perhaps of Laplace's *Exposition du Système du Monde* or of systems of interacting particles (molecules) in a gas or fluid or solid. Since the time of Faraday and Maxwell, of course, we include in any notion of system the electromagnetic field, which is an intrinsic part of an assembly of charges and currents.

To this day we start with simple static systems and it is enjoyable to see how Simon Stévin (1548–1620) dealt with these 400 years ago, in 1586. Known for general works on mathematics, mechanics, astronomy, navigation, military science and engineering, Stévin is perhaps best known for his discovery of the law of the inclined plane, which he demonstrated with his famous "Wreath of Spheres" (or *clootcrans*), a nice example of an early *Gedankenexperiment.*[1] By clever reasoning Stévin utilized the intuitive absurdity of perpetual motion—a system's starting spontaneously even as the configuration of its components is invariant—combined with symmetry considerations to give a logical proof of the equilibrium conditions for the inclined plane. Stévin's motto *Wonder en is gheen Wonder* ("It's a wonder and yet it is not a wonder") expressed his sense that the laws of mechanics are miraculous, although remarkably understandable. (See figure 1.)

Almost 100 years later, Otto von Guericke (1602–86), the mayor of Magdeburg, demonstrated the working of pumps and the effects of air pressure with his famous Magdeburg hemispheres. Like Stévin, von Guericke was active in public affairs, but he is remembered primarily for his invention of the air pump and his discovery of the elasticity of air. Von Guericke's systems of air at varying pressures in enclosed vessels were more sophisticated than inclined planes, but they were still describable by a small

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This schematic figure illustrating Stévin's argument about static equilibrium became his trademark. The weight of the spheres on an inclined plane is proportional to its length and is balanced by a force along the plane that is proportional to the height of the triangle. It follows that the force equals the weight times the sine of the angle between the inclined plane and the horizontal. **Figure 1**

number of variables and parameters (see figure 2). Yet another hundred years later, the measurements on the electrostatic interaction between charges undertaken by Charles Augustin Coulomb (1736–1806) remind us of systems that require a field description, implying a considerable broadening of the means that are needed to characterize a physical system. An illustration from Coulomb's works shows how he used the torsion balance he invented to measure the forces between charges. (See figure 3.)

Knowing your system is of particular importance in thermodynamics. Thus at the beginning of a standard textbook's section on thermal physics, we are told that "in analyzing physical situations we usually focus our attention on some portion of matter which we separate, in our minds, from the environment external to it. We call such a portion the system."[2] In a recent Reference Frame column on self-organized criticality and sandpiles in PHYSICS TODAY, Leo Kadanoff says that "a simple physical system might be defined as one that obeys simple laws" (March, page 9).

From systems to states

Just as we thought that the concept of a system was in hand, along come the developments of the 20th century, suggesting major conceptual revisions—both subtle and radical—of our notion of a physical system. General relativity, with its geometrization of mechanics, makes it quite awkward to speak of a system that is distinct from its environment. But quantum mechanics requires that we altogether rethink and reformulate the concept of the physical system. We learn that it is not constructive to imagine a quantum system only in its interaction with controllable external influences, but that we must also take into account some less analyzable interventions—usually referred to as "measurements"—which forces us to come to terms with the inherently nonlocal nature of physics at the quantum level.

The tools of quantum mechanics are state vectors (or just plain "states") or density operators and operators representing physical quantities ("observables"). A quantum mechanical state is usually said to be the state *of a system*, but the laws of (linear) quantum mechanics greatly limit the validity of such a characterization.

If initially we have two systems, A and B, each in a definite state, after the two systems have interacted it generally is no longer possible to consider either of them to be in a definite state even after the interaction has ceased. The two systems have infected one another, and their "entanglement" persists. (Henry Margenau apparently was the first to use the term entanglement in this context.) The most familiar example is the singlet state of two spin $\frac{1}{2}$ particles, or the analogous polarization state of two photons. This is the kind of entangled state of the system $A + B$ that is known to be incompatible with the conventional description of A and B as individual systems and that is illustrated in the growing number of Einstein-Podolsky-Rosen experiments, which show that some statistical correlations between A and B are undiminished even if the two parts A and B of an entangled system $A + B$ are widely separated.

In quantum mechanics we can no longer insist on thinking of a system as a physical arrangement that is capable of interacting with its environment or with other systems and also possesses enough integrity, identity and permanence to be fully characterized by its own internal properties when it is as isolated as we can make it. We realize that it is often impossible to distinguish sharply between "the system" and its environment, and we are motivated to think less about physical systems as objects or aggregations of objects with boundaries that separate

In a dramatic large-scale experiment, first performed in Magdeburg in 1657, von Guericke demonstrated the effect of air pressure on an evacuated cavity formed by two tightly fitted copper hemispheres. **Figure 2**

the system from its environment, and to think more about states. Instead of being surprised that physical observables can remain correlated even when they refer to (sub)systems so widely separated that no information can pass between them, we now are led to wonder under what special conditions entangled states become separable so that correlations between some particular subsets of observables will not be apparent. In this light, Einstein-Podolsky-Rosen experiments and questions of quantum mechanical measurement ("collapse of the wave function") are stripped of some irrelevancies, such as the impression that some kind of interaction at a distance between *subsystems* is essential for our understanding.

Furthermore, the relation between classical and quantum physics can be elucidated. We learn to speak of "classical states" rather than "classical systems," localized states rather than confined systems, and separable states rather than isolated systems. In each case we can establish quantitative criteria (to any desired degree of accuracy) for identifying these states. As the term "classical" becomes an attribute of a state that obeys the laws of classical physics, there is no longer any confusion between being "classical" and being "macroscopic." A state can then be macroscopic without being classical, and classical without being macroscopic.

In shifting the emphasis from systems to states, quantum mechanics also teaches us that our common way of talking about a system—such as a particle—as "having" (or "possessing") a momentum p, or any other physical property, is of limited validity. Rather, it is more appropriate to say, in a somewhat contorted fashion, that "momentum p is possessed by a particle" or "the momentum level p is occupied." At first this seems to be merely a slight semantic matter, hardly very profound. But the shift from an active to a passive mode avoids attributing fictitious and ephemeral characteristics to objects, such as particles, and it keeps us out of trouble, for instance when talking about the vacuum (state). It induces us to use the language that is precisely tailored to the quantum mechanical description of systems of many identical particles and of fields. (Even in a fully classical description of electrons scattering from atoms, it is not always easy to tell the "environmental" electron from the atomic electron, indicating a degree of entanglement.[3])

It is not surprising that the teaching of physics at the introductory level has not kept pace with the conceptual changes that have taken place during this century. There are formidable obstacles in the way, arising mainly from the abstract nature of much of contemporary physics, and it will take a long time before these ideas, however familiar they may be to the practicing physicist, can be expected to permeate the introductory textbook literature. Fortunately, there is some ferment in the physics teaching community, and the conceptual changes for which 20th-century physics has been responsible are at last receiving attention from some physicists concerned with education, especially the younger ones.

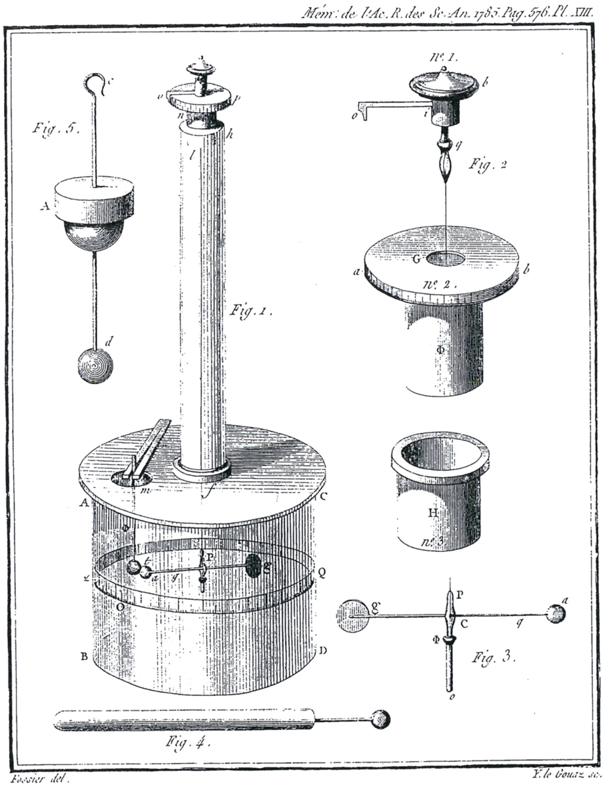
New APS constitution

I would like to spend the balance of my report describing a dynamic physical system that has grown large and complex, sometimes even a bit chaotic. It is our American Physical Society. Happily, it seems to be a reasonably stable system, even as it expands and becomes ever more venturesome.

Three major developments of the recent past deserve to be mentioned here: the new APS constitution; the changes among our operating officers; and the planned relocation of APS headquarters.

Last fall a new constitution for the society was approved. The objective of APS is still "the advancement and diffusion of the knowledge of physics." But a number of structural changes were made that were probably long overdue. Most revisions were motivated by the growth of the society and by the simultaneous diversification and specialization of our discipline (see James A. Krumhansl's article on unity in the science of physics in PHYSICS TODAY, March, page 33).

It is neither new nor news that APS accomplishes much of its mission through its subunits, the divisions and



Coulomb applied his torsion balance to the measurement of electrostatic attraction and repulsion and to the demonstration of the law that bears his name. **Figure 3**

topical groups as well as the geographic sections. Many APS members choose not to be identified with any particular subunit. Nevertheless, most of the work APS does to foster the advancement and diffusion of physics is carried out in the divisions and topical groups.

The new constitution acknowledges that the relatively intimate and familiar setting of the topical groups and divisions is the primary source of the society's vitality. At the same time it provides for a regular process by which people with shared specialized scientific concerns may form a new topical group and, as the subfield matures, let it evolve into a division. This structure makes it possible for a very large number of physicists to take an active part in the governance of their professional organization.

Ultimate responsibility for the society and its policies rests in our council. The new constitution underlines this principle. By delegating to a representative 14-member executive board the job of overseeing the daily affairs of the society, the council will now be able to devote more time to debates on key policy issues. Since the new council will be fully established only in January 1992, it is too early to draw definitive conclusions about the efficacy of the new arrangement, but we have already seen encouraging signs. It is hoped that the council will be able to deliberate more effectively on the issues that really count, such as the quality of APS publications, our concern with physics education and statements on public policy.

The continuing difficulties faced by research physicists in raising funds for their work, in conjunction with demographic statistics,[4] produce some uncomfortable questions, and we should address them: How many physicists will there be in the next decade? What will they do? Can they expect adequate research funding? What can APS do to assist them in establishing productive careers?

The composition of the new council was arrived at after long discussions, which involved everyone who wanted to participate. Large divisions will now have more than one councillor, and there will also be more general councillors than we had before, elected by the entire membership. The much-debated 3% rule, which puts a floor under the membership of every division and now threatens some of the smaller divisions with a loss of their divisional status, has caused some consternation (see PHYSICS TODAY, June, page 124). Otherwise, however, the transition to the new regime of our 1990 constitution appears to be progressing smoothly. This is not the time for arguing the pros and cons of the 3% rule, but it should be remembered that the figure itself was set in a bylaw that was made by the council and that can be changed by the council. It would appear to me desirable to wait a while and gain some experience before tampering with that admittedly arbitrary figure.

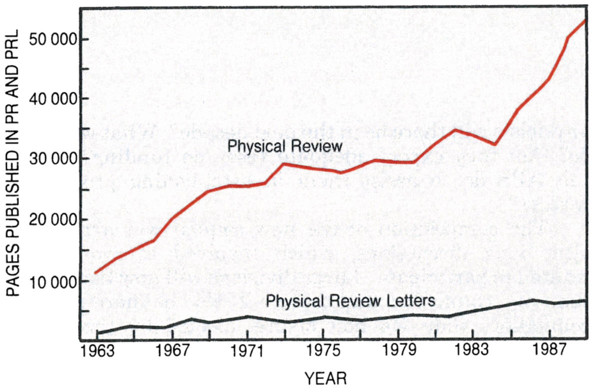
Changing of the guard

The team of operating officers that oversees the implementation of the council's policies consists of three physicists: the executive secretary (not a chief executive officer, as in some scientific societies), the treasurer and the editor in chief. This arrangement has served the society well for some time now, and it is retained with only minor changes in the new constitution. But by the end of this year, two of the three operating officers who have guided the fortunes of APS—one for more than a decade, the other for nearly three decades—will have retired.

Bill Havens, the retiring executive secretary, and Dave Lazarus, the retiring editor in chief, are leaving behind a healthy and flourishing APS enterprise. The extent to which their lives became commingled as officers of APS was recently described in a tribute by Lazarus to Havens (PHYSICS TODAY, May, page 59). Under their leadership, and with the prudent management of our treasurers, every quantitative indicator of APS activity has shown enormous growth. The increase in APS membership, which during my time as a physicist has gone from less than 10 000 to the present 42 000, has been matched by similar growth in the APS budget, and in publications (see figure 4). Such success exacts a price, and the revised constitution attempts to ease some of the society's growing pains.

The challenge for our new operating officers is to maintain and foster the spirit of collegiality, trust and openness that has been characteristic of our society since its founding in 1899, while they adapt some of our methods of doing business, which were appropriate for a much smaller and less diverse society, to the demands of the institution's second century.

It seems to me that we can think of APS as a grand physical system, with all the complications inherent in that concept. Perhaps instead of speaking of APS as a system it would be more appropriate to refer to the state of APS. After all, there is no way of isolating APS as an institution from its environment, the physics community. From the beginning APS has depended on physicists for its governance and operation. Physicists, to whom APS belongs, must continue to bring their problem-solving skills to bear on how to keep the journals healthy, how to



In recent history, it took 25 years for the membership of APS to double, but the size of *Physical Review* and *Physical Review Letters* doubled in just 10 years. Manuscripts submitted from outside the US have accounted for much of this growth. **Figure 4**

optimize the scientific meetings, how to assist the next generation of physicists in developing productive careers, and how best to champion the cause of a strong base of physics research and physics education, consistent with the kind of good citizenship that our new vice president, Donald Langenberg, called for in his address as the retiring president of AAAS. "What is important about science and the technology it spawns is what it contributed to enhancing the quality of human life," Langenberg said. "To engage ourselves in the struggle for the resources and conditions needed to strengthen science and technology's capacity to perform that essential function is hardly narrow self interest. It is our civic duty."[5]

A veritable army of volunteers has given the society its strength, its character—not to mention the wholesome effect their contributions have had on the APS budget. The new constitution assumes that we will continue in this tradition. However, if we are to do well all that needs to be done, we should most certainly take advantage of modern management techniques for the society. We are fortunate to have among our membership a healthy mix of academic, industrial and government-laboratory physicists, with complementary traditions and varied experiences.

We all know that to do good physics it is essential to choose the right kind of problem. Similarly, we must be discriminating in our choice of issues that we take on in The American Physical Society. There are so many tempting projects that it is easy to overextend ourselves. Fortunately, our democratic deliberative bodies, especially the council and the Panel on Public Affairs, have been vigilant—some might say conservative—in insisting that the initiatives APS undertakes maintain the highest standards of professionalism, objectivity and integrity. We should never depart from those principles.

On the other hand, I submit that we should be catholic when it comes to providing a home in which scientists of whatever persuasion or specialization who want to pursue the advancement and diffusion of the knowledge of physics can feel comfortable. Occasionally, as some of the letters to PHYSICS TODAY attest, the society has been regarded as arrogant and unsupportive of the broad spectrum of physics.

I am reminded of a glossary of phrases produced by one of our colleagues and suitable for use by physics spouses at cocktail parties. This was some years ago, and one entry was: "Yes, but is it renormalizable?" Another one—of which I am thinking in the present context—was: "Yes, but is it really physics?" We must never relax our high standards of quality, but I suggest that it does not do us credit to be narrowly judgmental in allowing certain scientific activities into the temple of physics and excluding others. Certainly Unity Day is an occasion for being broad-minded.

Education forum, relocation

It is gratifying also that the society has now created a Forum on Education, something that would have been unthinkable not too many years ago. I trust that in doing so we are not just paying lip service to a currently popular trend, but that we will go about this with a most serious purpose and hand in hand with AAPT. The forum's purpose is to provide opportunities for physicists, especially nonacademics, to participate in educational activities.

As you know, the council decided last year to move the APS headquarters from New York City to the environs of Washington, DC, which will provide APS with an opportunity to enhance services to its diverse membership. The move will take place jointly with that of the American Institute of Physics, and it will also allow us to colocate with AAPT and possibly other AIP member societies.

After almost 100 years of existence in New York, such a move won't be easy or painless, especially for us opera lovers, but there is an urgent need for more and better space. We have a chance to build a new American Center for Physics on a beautiful tract of land in College Park, Maryland, about ten miles from downtown Washington on a Metro line that is now under construction, near the University of Maryland campus.

The design of the new building is still quite open, but if everything goes along at the present pace, the move should occur within two to three years. We welcome suggestions from our members for what facilities they would like to see in the new building. We hope that it will be a beautiful as well as functional American Center for Physics, attractive to visitors and itinerant volunteers. We look forward to celebrating in 1999 The American Physical Society's 100th birthday in it.

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