publication list, applicants were instructed to submit their five best papers from the last three years (the numbers are arbitrary), the incentives would actually be reversed. Little would be gained from writing more papers, other than personal satisfaction, as the people evaluating the research would not see those extra papers. In particular, there would be no incentive to write two nearly identical papers or to break up a subject into many small papers. And since referees might *read* the papers, there would also be little incentive to do the opposite and write indigestible "kitchen sink" papers with many different projects stuffed in.

Such a system would be easy to implement. Only the relatively small number of granting agencies would have to agree to adopt a common set of rules for applications. They could enforce those rules by automatically deleting from applications any publication list that might "accidentally" find its way in. One might wonder whether grant reviewers would not be swamped by a rising tide of papers to read. To some extent, their problems could be eased by adopting another rule that would limit the text of an application to, say, four pages. Again, the rule could be enforced by mechanically deleting extra pages before sending out proposals for review. Far from being utopian, such a system has been partially implemented here in Canada by NSERC (the rough equivalent of NSF). NSERC does everything suggested above except that it still allows a publication list in addition to copies of one's best papers.

The above suggestions might seem to stray from the topic of computerizing libraries, but I believe that they go to the root of the problem that so worries Mermin and many others. Although growth is inevitable, we can control the worrisome trend toward repetitious and serial publication that has been responsible for a good part of the continuing explosion in the number and size of journals.

JOHN BECHHOEFER
Simon Fraser University
5/91 Burnaby, British Columbia, Canada

Your readers may be interested in a partial solution to the problems described by N. David Mermin. He points out that few people "have access to preprints, the current avenue of serious communication." One way to address at least *that* problem successfully has been demonstrated by *High*-T_c *Update*, an internationally distributed newsletter devoted to high-temperature superconductivity preprints.

High-T_c *Update* was begun in May 1987 at a time when it seemed that superconductivity breakthroughs were occurring faster than they could be faxed. In response to the urgent need to ensure rapid, reliable communication of research and to expand the network of researchers communicating with one another, the Department of Energy asked the Ames Laboratory to set up an information center and publish a newsletter.

The core of the newsletter is a list of preprints received during the previous two weeks. Each entry includes the preprint title, the address of the first author (including phone, fax and e-mail, if available), information about where the paper was submitted or presented, and key words and PACS numbers (if available). We do not referee the papers. The newsletter begins with "Nota Bene," a section highlighting some of the research described in the 100-odd preprints in each issue. Other sections include news, current events, resources and "FYI" (For Your Information).

High-T_c *Update* is published twice a month and is distributed both as hard copy (by first-class mail or airmail) and as electronic mail (sent over e-mail networks or downloaded from a dial-up account). It is available without charge.

ELLEN O. FEINBERG
Project Director/Editor, High-T_c Update
JOHN R. CLEM
Science Editor, High-T_c Update
Iowa State University
7/91 *Ames, Iowa*

Detailed Breakdown of Broken Symmetry

The following is my contribution to the broken symmetry debate (May 1990, page 117; February 1991, page 13).

In general, symmetry with respect to a transformation group G acting on a physical system means that time translations and group transformations commute. For continuous transformations this may be expressed infinitesimally by a vanishing of the commutator $[H,G]$ of the group G with the generator of time translations, the Hamiltonian H. Thus symmetry is a property of the algebra of observables.

According to the principles of quantum theory a state of a physical system is described by a positive linear functional ω on the algebra of observables, and one naturally arrives at the question of how the concept of symmetry is realized on states.

One usually starts by looking at the ground state of a system, that is, the vacuum—the state in which the expectation value of the Hamiltonian is minimal. Sometimes it happens that there is a multiplicity of such states, naturally transformed into one another by symmetry transformations $g \in G$. In addition, it may happen that each of these states is invariant under the transformations belonging to a subgroup $K \subset G$. Thus the "manifold of vacua" is isomorphic to the homogeneous space G/K.

To get a unique vacuum one picks "spontaneously" one point of the vacuum manifold. In the language of algebras of observables we may say that a symmetry transformation (considered as an automorphism of the algebra of observables) changes the representation. This vacuum-representation-noninvariant realization of a symmetry may be called the Nambu–Goldstone realization and is often dubbed "spontaneously broken symmetry."

In this case, the spectrum of excitations does not form a multiplet spanning a linear representation space of G. Rather, due to results obtained by Heisenberg, Yoichiro Nambu and Jeffrey Goldstone, we encounter massless (or long wave) excitations, which are naturally associated with a nonlinear realization of the group G as a transformation group on the curved space G/K. In fact the Nambu–Goldstone modes may be viewed as excitations in the tangent space of this manifold.

The archetype of this phenomenon is the Heisenberg ferromagnet, for which $G = \mathrm{SO}(3)$ and $K = \mathrm{SO}(2)$. The manifold of vacua in this case is the 2-sphere $\mathrm{S}^2 = \mathrm{SO}(3)/\mathrm{SO}(2)$, each point of which may be visualized as a classical spin. The picking of one point of the vacuum manifold corresponds physically to spontaneous magnetization in a certain direction. Another prominent example is the spontaneously broken chiral symmetry of the nonlinear sigma model. Here we have $G = \mathrm{SU}(2)_\mathrm{L} \times \mathrm{SU}(2)_\mathrm{R} \cong \mathrm{SO}(4)$ (where $\cong$ denotes locally isomorphic), $K = \mathrm{SO}(3)$ and $G/K = \mathrm{S}^3$. The massless bosons are the pions in this case. Evidently, in reality this Nambu–Goldstone symmetry is only approximate (that is, it is explicitly broken). The antiferromagnet may also be modeled in this fashion, but the breaking is from SO(3) down to the discrete subgroup Z_2.

Superconductivity (treated in a gauge-invariant way) does not provide an example of the Nambu–Goldstone mechanism, since the Nambu–Goldstone mode does not correspond to a

propagating "real" quasiparticle (for example, a plasmon). Rather, this mode has much in common with what is called a "ghost" in field theory (though the two are by no means identical). In fact superconductivity is—in some sense—"the counter-example" to the Nambu–Goldstone mechanism (high-energetically speaking, the evasion of a no-go theorem led to electroweak theory), since massless bosons are absent from the spectrum. The Stückelberg-Anderson-Higgs-Kibble mechanism absorbs the would-be Goldstone-boson gauge degree of freedom into the Meissner (massive photon) effect. By the way, the would-be Goldstone boson χ may be recovered if we reformulate the London equation in a gauge-invariant way by using $j_\mu \propto A_\mu - \partial_\mu \chi$ and imposing the correct transformation law on the field χ. In the Lorentz gauge, we immediately get $\partial_\mu \partial^\mu \chi = 0$. On the other hand, antiferromagnetism is a good example of spontaneously broken symmetry as long as it is not treated as a gauge theory.

Let me close with a short comment on Philip W. Anderson's letter (May 1990, page 117). It is true that in ferromagnetism the ground state is an eigenstate of a continuous symmetry, but only of the little group $G = \mathrm{SO}(2)$, that is, the remaining symmetry. Broken symmetry indeed will occur if the ground state is not an eigenstate of the original group $G = \mathrm{SO}(3)$. One must never forget that we are dealing with nonlinear representations.

Finally it is worth remarking that there are attempts to reinterpret photons, gravitons and even phonons as Nambu–Goldstone bosons (in the case of the phonons, as the Nambu–Goldstone bosons associated with a breaking of the Poincaré group down to the crystal group). However, there are problems related to the fact that the symmetries considered in this context are space–time symmetries, so that the definition of the ground state is more involved.

Chapter 7 of Heisenberg's *Einführung in die einheitliche Feldtheorie der Elementarteilchen* (S. Hirzel Verlag, Stuttgart, 1967) provides a very good account of broken symmetry with reference to the Heisenberg ferromagnet.

RALF D. TSCHEUSCHNER
University of Hamburg
4/91 *Hamburg, Germany*

ANDERSON REPLIES: For once, I am speechless.

PHILIP W. ANDERSON
Princeton University
8/91 *Princeton, New Jersey*

Encouraging Electricity

John H. Gibbons and Peter D. Blair observe in their article on the "US Energy Transition" (July 1991, page 22) that although the growth in the consumption of electricity has decelerated over the past two decades, it continues to keep pace with the growth in the gross national product. This has occurred despite reasonably strenuous and presumably somewhat successful efforts to promote and subsidize the conservation of electricity.

The continued growth in electrical usage will not be environmentally disastrous provided that a larger fraction of the electricity is generated from renewable resources and nuclear power. Encouraging progress in the development of renewable sources of central station electricity and the fact that constraints on the growth of nuclear power are political rather than technological suggest that this objective should be achievable. The problem of nuclear waste management, which is a major cause of opposition to nuclear power in the US, has been successfully finessed in France and Japan by the avowed plan to eventually deploy plutonium recycling and to deal with the remaining wastes at some time in the distant future when both the radioactivity and the intensity of public opposition to waste management are expected to have decayed. It is furthermore to be hoped that Sweden's plan to dismantle its nuclear reactors will proceed on schedule, since this would provide an early demonstration that plans for managing spent fuel and other radioactive components of nuclear plants can be carried out expeditiously and safely when environmentalists and politicians impose no major impediments.

From the above point of view, the central goal of the US energy program should be to further broaden the use of electricity as a replacement for fossil fuel combustion in transportation, in industry and in homes. This is a crusade in which proponents of solar power, wind power, fusion and fission may be able to stand shoulder to shoulder. Much needs to be done to encourage the development of the required infrastructure and to exploit opportunities for innovative scientific research that might facilitate the greater use of electricity.

HENRY HURWITZ JR
7/91 *Schenectady, New York*

GIBBONS AND BLAIR REPLY: We are sympathetic with Henry Hurwitz's interest in seeing electricity continue