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casual remarks addresses the actual question that was under discussion in the May 1990 letters column. Paul Langacker and Alfred K. Mann might or might not agree with me on the dictionary definition of "broken symmetry" for the purposes of solid-state physicists, but what was in question was the meaning and use of the phenomenon in particle theory. Neither Sir Rudolf Peierls nor Thomas A. Kaplan refers to the original work by Yoichiro Nambu and G. Jona-Lasinio or by Steven Weinberg and his colleagues, which are in fact the only relevant references on this question.

In this work the property that is used is the actual change in symmetry of the excitation spectrum, which is consequent on the order parameter's not being a conserved quantity, that is, not commuting with the original Hamiltonian. Therefore excitations—read "particles" in the electroweak or chiral symmetry-breaking theories—are no longer classified by representations of the original group. In the work of Nambu and Jona-Lasinio, for instance, the original group includes chiral symmetry, while the resulting particles—pions and nucleons—do not have a chirality quantum number. This is analogous to BCS theory, where the Hamiltonian is charge conserving but the quasiparticles do not create charge eigenstates. In the ferromagnetic case the excitations—spin waves—can be chosen to create states with a definite spin quantum number, so the analogy to ferromagnetism is flawed. There are no particle theories with spontaneously broken symmetries of the conserved type. It was this point I wished to make, and it is this definition of "broken symmetry" which is natural in the context of particle theory. (It is also useful in understanding the sometimes mysterious properties of excitations in solid-state systems, such as that phonons do not have a true momentum quantum number, nor antiferromagnetic spin waves a fixed spin.)

Let me discuss the two letters individually. Kaplan's use of my own words against me is a tactic not worthy of a reply. The rest of his letter is a dictionary definition for solid-state physicists, combined with a discussion essentially equivalent to part of that given in my original 1952 paper in which, I believe, this kind of question was first correctly treated; Nambu and Geoffrey Goldstone's original work is also useful, in that they first made explicit the idea of quasidegeneracy and coined the phrase "broken symmetry"—for which service, I should imagine, they earned the right to define the words.

Peierls's discussion seems to be seriously incomplete, in that he misses the large quasidegenerate manifold of states with spin quantum numbers from 0 to N: In the idealized system, these states are rigid rotor eigenstates, with energies $J(J+1)/N_\chi$. He seems to have read neither my original paper on this question nor the relevant references by Nambu, Goldstone, Abdus Salam and Weinberg, and I strongly recommend he do so.

Since the entire question is one of particle, not solid-state, theory, I hope that some particle theorist will weigh in with an opinion.

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Teaching Physics to Poets, and Vice Versa

How does one learn to appreciate fine cuisine: by going into the kitchen and apprenticing under a great chef, or by visiting many restaurants and sampling a variety of dishes?

If I understand Leon Lederman's Reference Frame column "Physics for Poets" (July 1990, page 9), a nonphysicist's appreciation of the beauty and excitement of physics must be acquired in the kitchen, that is, through problem solving and laboratory experimentation. This time-honored viewpoint ignores the difficulty that ordinary folks have in casting elementary problems in terms of the simplest mathematics. It also ignores the fact that so many of the problems and experiments examined in low-level courses are not particularly interesting to poets and philosophers.

Now, as in the past, the guiding principle seems to be that somehow the pain a nonphysicist experiences in even attempting to solve physical problems will be transformed into insight and appreciation. To the contrary, my personal experience was one of acute indigestion.

Perhaps it's time for the physics community to try the opposite extreme: Invite the poet and philosopher to sit down at the best table in the house and sample the rich fare of contemporary physics, the same stuff that is served in issue after issue of PHYSICS TODAY. The classical basis for these concepts might be introduced qualitatively by imaginative use of interactive computer graphics. The poet could, for example, play with the Navier–Stokes equations and observe the beautiful patterns that emerge as boundary conditions and other parameters are changed. And if he can't derive the equations, so what?

I don't see how students taking such a course could help but be captivated by the world of physics. Many, out of interest, would probably continue to keep up with what's happening in the field, and those who end up in the political arena would better understand the importance of funding this project or that. Certainly all would emerge with a much deeper understanding of the role physics has to play in approaching the global problems with which mankind is faced today.

Of course there is always the danger that if the course was too successful, the starry-eyed physics major might also wish to enroll, thereby earning an easy credit.

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I enjoyed Leon Lederman's "Physics for Poets" very much and agree with him wholeheartedly: We must do better at educating everyone on the importance and relevance of science in today's world. But the other side of the educational coin also needs addressing. I would like to propose a course called "Poetry for Physicists," with a parallel goal to "Physics for Poets"—namely, teaching what physicists should remember about poetry (or history or music or whatever) in 10 or 15 years, when we are working on global warming or creating the next Stealth bomber. In the past few years I have noticed that ethics courses in business colleges are becoming more popular. It seems to me that ethics for scientists is at least as important—perhaps even several orders of magnitude more important.

In my academic utopia, we physicists would first sharpen our intellectual scalpels on the problems of what it means to be a human being before going at what it means to be a hydrogen atom. And if physics departments let in a little more liberal arts, perhaps the liberal arts departments would return the favor. Then we would all be able to remember, in 10 or 15 years, why it was that we bothered to study at an institute of higher learning, and not simply a trade school.

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Apropos Leon Lederman's important plea, the following should be of help in the economics of teaching the methods of physics to large numbers of citizens: Include among lecture demonstrations several in which the student makes all the observations from her or his seat and then plots and analyzes those very numbers.

I've performed half a dozen such experiments with those MIT freshmen who chose our nearest equivalent to "Physics for the Citizen." Another such experiment was done with visiting high school science teachers, who acted then as students. In it the student measures the amplitude and period of a pendulum versus time, and its period versus amplitude, height and the composition of the bob. The rulers and clock need to be very large so as to be readable from anywhere in an auditorium seating hundreds of students, and the tick when the bob interrupts a light beam needs to be loud. This large scale allows even a distant observer to feel a strong, unmediated interaction with the experiment.

The students take down the numbers they are directed to observe and then analyze, plot and write up the results as homework.

Since many students need to be taught the most basic basics—for example, to interpolate ruler readings between marks separated by 10 centimeters—it probably would be good to repeat one or more of the experiments after grading to teach how results can be sharpened by care. A difficulty may be lack of experience with experiments and data analysis on the part of many recitation instructors or other graders, and inability of lecturers to omit material to make way for the very time-consuming process of learning to take and analyze data.

Of course, real laboratories are much better, but to be good they require much more teaching talent and time per student than do lecture demonstrations. It is unrealistic to expect first-rate physics laboratories to be required of most students at most US institutions.

Fortunately, the experience of handling equipment is probably not necessary for fairly good science citizenship. As a feasible substitute, we can try merely(!) to teach what it is to make reliable observations and to carry out clear analyses of numbers, with the equipment itself manipulated only by the lecturer.

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Onsager's Outside-In Intuition

Another counterintuitive notion!

Graham R. Fleming and Peter G. Wolynes (May 1990, page 36) mention a 1976 conference at which Lars Onsager argued that in the process of electron solvation "the solvent far from a *localized* electron would relax to equilibrium faster than the solvent near the electron, and so the solvation structure around the electron would form from the outside in! . . . We shall never know exactly how he came to this counterintuitive notion about solvation dynamics because he died shortly after the meeting" (italics added).

The conference was the 1976 International Conference on Electrons in Fluids, and the particular remark referred to by Fleming and Wolynes is on page 1819 of the refereed proceedings[1]: "Let me argue for the proposition that the 'snowball' forms from the outside in. If we regard the *trap formation* as a process of dielectric relaxation around a *delocalized* electron, this will proceed at a rate given by the longitudinal relaxation time $\tau_L = \tau_D \epsilon_\infty / \epsilon_0$ in the distant part of the fluid (outside the counteracting region of localization), and the *equilibrium* polarization in the immediate vicinity is established last" (italics added). Joshua Jortner replied that this was similar to a proposal that the *initial step* in electron localization was the fast response of the polar medium to a large polaron in an *extended* state, involving the buildup of the long-range polarization field. In the vernacular this was known as an electron's "digging its own hole."

Some of us preferred a model in which a delocalized electron suddenly becomes localized by an inelastic event in an already existing defect (trap) in the local structure of the fluid. The resulting jolt of charge-dipole torque then causes solvent rearrangement near the center of charge. The rearrangement rapidly spreads outward, and then more gently washes back inward as the final adjustment that achieves equilibrium with the bulk liquid. The idea of the back-inward phase of the relaxation was inspired by Onsager's remark. It is an attempt to take into account the enormous resistance of the bulk liquid structure to a sudden, drastic rearrangement in a local section of it.

Onsager was intuitive, and the molecular dynamics simulators got the quotation wrong! If they continue their elegant work they might find the back-inward phase of the liquid rearrangement around a suddenly introduced charge.

The word "counterintuitive" simply means that someone is wrong.

Reference

1. Can. J. Chem. **55**, 1795–2277 (1977).

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Fleming and Wolynes reply: No one disputes Lars Onsager's level of intuition. We use the term "counterintuitive" to mean "against the naive intuition of ordinary mortals." Gordon Freeman is correct that Onsager's original suggestion dealt with the localization of the electron. Our memory was clouded since Onsager's contemporaneous work with Joseph Hubbard suggests the same set of time scales for localized charges.

As to the scientific facts, we feel it is likely that the outside-in formation picture holds for some solvents. Indeed, a lot of the analytical work in this area described in our article suggests this. The current molecular dynamics results for water suggest that in this liquid formation of the structure occurs in the anti-Onsager way around localized charges: inside first, outside last. Nevertheless, as we also pointed out, the current molecular dynamics calculations do not include the polarizability of the water directly and thus cannot be considered definitive. It is not altogether out of the question that the outside-in picture will be vindicated in the last analysis by molecular dynamics.

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Emigré Scientist Aid: Threat to Civil Rights?

In his letter to the editor (October, page 121) Alexander Kaplan proposes a program involving a combination of Federal funding and university support to create research positions that would be open to immigrant scientists only. He has in mind Soviet emigrés in particular, but would also include immigrant scientists from Eastern Europe and China.

Let's be honest. What Kaplan wants is discrimination based on national origin! His proposed program would violate the Equal Opportunity Act, which is one of the great cornerstones of American civil rights legislation. The research positions he wants to create would be open to Soviet emigrés but not to American blacks or American women. Soviet