Symmetry Breaking

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Book review

Symmetry Breaking
F Strocchi (ed R Beig, W Beiglböck and
W Domcke *et al*)
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One of the most fruitful and enduring advances in theoretical physics during the last half century has been the development of the role played by symmetries. One needs only to consider SU(3) and the classification of elementary particles, the Yang–Mills enlargement of Maxwell's electrodynamics to the symmetry group SU(2), and indeed the tremendous activity surrounding the discovery of parity violation in the weak interactions in the late 1950s. This last example is one of a broken symmetry, though the symmetry in question is a discrete one. It was clear to Gell-Mann, who first clarified the role of SU(3) in particle physics, that this symmetry was not exact. If it had been, it would have been much easier to discover; for example, the proton, neutron, Σ, Λ and Ξ particles would all have had the same mass. For many years the SU(3) symmetry breaking was assigned a mathematical form, but the importance of this formulation fell away when the quark model began to be taken seriously; the reason the SU(3) symmetry was not exact was simply that the (three, in those days) quarks had different masses.

At the same time, and in a different context, symmetry breaking of a different type was being investigated. This went by the name of 'spontaneous symmetry breaking' and its characteristic was that the ground state of a given system was not invariant under the symmetry transformation, though the interactions (the Hamiltonian, in effect) was. A classic example is ferromagnetism. In a ferromagnet the atomic spins are aligned in one direction only—this is the ground state of the system. It is clearly not invariant under a rotation, for that would change the ground state into a (similar but) different one, with the spins aligned in a different direction; this is the phenomenon of a degenerate vacuum. The contribution of the spin interaction, s1.s2, to the Hamiltonian, however, is actually invariant under rotations. As Coleman remarked, a little man living in a ferromagnet would have to be rather clever to recognize that the particle interactions were rotationally invariant. Nambu and Goldstone showed that the spontaneous breakdown of a (continuous) symmetry implied the existence of massless scalar particles, referred to as Nambu–Goldstone bosons, or simply Goldstone bosons. Meanwhile Anderson, in his study of (non-relativistic) superconductivity, showed that the exclusion of magnetic flux (Meissner effect) corresponds to a finite range for the electromagnetic field and hence to a 'massive photon'. In a relativistic context Englert, Brout, Guralnik and more particularly Higgs showed that a spontaneous breaking of a gauge symmetry resulted in a massive, instead of a massless, gauge particle and no Goldstone particle; in the jargon of the day, the massless gauge particle had 'eaten' the massless Goldstone boson and become massive; exactly Anderson's observation. It is this phenomenon which has been invoked so successfully to explain the masses of the W and Z bosons of weak interactions. Spontaneous symmetry breaking, therefore, has played a major role in the development of the Standard Model of particle physics, and it has also proved an important tool in condensed matter physics, for example in the understanding of phase transitions. At the same time, however, in the understanding of most (or all) particle physicists, and perhaps also condensed matter physicists, the notion of spontaneous symmetry breaking has been inexorably linked to that of a degenerate vacuum.

This is the background and the starting point for Strocchi's book. Recognizing the power and importance of the concept of spontaneous symmetry breaking in theoretical physics, he defines it in a more refined and general way than usual. 'Despite the many popular accounts', he writes, 'the phenomenon of spontaneous symmetry breaking is deep and subtle and it is not without [reason] that it has been fully understood only in recent times.' Strocchi's main emphasis is on the fact that the loss of symmetric behaviour requires both the existence of non-symmetric ground states and the infinite extension of the system. The book is divided into two parts, treating respectively the classical and quantum regimes. In classical field theory the symmetry breaking is explained in terms of the occurrence of disjoint sectors, or different phases, of a physical system. In the quantum regime the mechanism is characterized by a symmetry breaking order parameter, for which non-perturbative criteria are discussed, following the work of Wightman, in contrast to the

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usual Goldstone perturbative strategy. Strocchi's main interest is in condensed matter, rather than particle, physics, and the topics he covers include spin systems, Fermi and Bose gases and finite temperature field theory.

The book is based on lectures given over a number of years. It is written in a pleasing style at a level suitable for graduate students in theoretical physics. While mathematically proper, it is not forbidding for a physics readership; the author is always aware this subject is a branch of physics. It should make profitable reading for many theoretical physicists.

L H Ryder
Department of Physics, Kent University,
Canterbury, Kent CT2 7NR, UK

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