How to say sorry graciously

Mistakes will happen, so that retractions will continue to be necessary. Two physicists have now produced a model of how the task should be tackled.

RETRACTION has become a loaded word, which journals and their contributors alike abhor. As things are now in the United States, there is even a danger that the mere appearance of a retraction will be regarded by a congressional committee or by a self-appointed watchdog as a signal for an inquiry into what has been going on. That is one reason why there should be some rejoicing that it is still possible to publish a full, even a fulsome retraction without bringing down the house on one's head. What has happened is that two physicists at the University of Maryland at College Park (almost in suburban Washington) have retracted the conclusions of an article that appeared last year in no less a journal than *Physical Review Letters* (**59**, 2507; 1988), but they have done so in such an open fashion that even their sternest critics will be disarmed.

The tenor of the retraction can best be judged from the sentence towards the end in which the authors, O.W.Greenberg and R.N.Mohapatra, say: "We are grateful to Rudolf Haag for warning us of the error of our ways". They then go on to thank another colleague for drawing their attention to an article in the Soviet literature which, if read in time, would also have warned them off. They acknowledge in their retraction (*Phys. Rev. Lett.* **62**, 712; 1989) that many people have already embarked on experiments to test their earlier theory. But the best guess seems to be that those who have started down that road will continue, if only because the issue is in itself intrinsically interesting.

The question is whether there can be violations of Pauli's exclusion principle which, applied to electrons, forbids the simultaneous presence of two particles in the same state. An entirely equivalent way of putting this restriction is to say that the complete wavefunction of a system of several electrons (or other particles of the family called fermions) must be antisymmetric with respect to the exchange of any two of them.

But that formulation has the advantage of suggesting that the wavefunction of a system of several bosons must be symmetric with respect to the exchange of random pairs of particles. The practical consequences are of course considerable. Fermions obey Fermi statistics and bosons (such as photons) obey Bose–Einstein statistics, which explains why the free electrons in a metallic conductor make only a negligible contribution to its specific heat.

There is a third formulation of Pauli's principle which field theorists find more useful. A particle field, say some arbitrary distribution of radiation (photons), can be conveniently represented with reference to the dynamically possible states of a single photon in the available space. The simplest way of cataloguing the states is by means of the multiply infinite set of states defined by the standing waves which can exist within whatever space is accessible, each of which corresponds to a simple harmonic oscillator whose frequency corresponds to that of the radiation (when the bosons are photons).

Starting from that point and the principle that, in quantum mechanics, observable quantities are operators, the field theorists have fashioned a formalism in which the actual state of a system, which should be a specification of the numbers of particles in each of the possible oscillatory states, can be built up from the interaction of elementary operators, one set for each possible state, which have the effect either of creating or getting rid of a particle from that state. The creation and annihilation operators are the life-blood of field theory.

They are also the simplest means by which departures from Pauli's principle can be handled. For it is clear that the creation operators for fermion and boson fields must have very different properties. Two fermions cannot be in the same state, which means that although the effect of a creation operator on an empty fermion state is to fill it with a single particle, Pauli's principle implies that a second operation on the same state must be a nonsense. But with bosons, the creation operators must plainly behave differently, because there can be many particles in the same state. The algebra that arises by forming the products of several of these operators is simple but intriguing.

Greenberg and Mohapatra's original goal was to study small departures from Pauli's principle. Large departures would not have been surprising in the sense that there is a theory (going back to the 1950s) allowing for particles (which apparently do not exist) with properties intermediate between bosons and fermions, and called parafermions and parabosons. And, of course, they suggested experiments to tell how big the departures are, or at least to define bounds for them.

Designing experiments is not as difficult as it may seem. If, for example, there is a chance that a single fermion state may occasionally hold two particles, it should be possible to discover that X-rays emerge from conductors carrying electric current, as electrons are occasionally captured into inner energy levels which temporarily violate Pauli's principle. Greenberg and Mohapatra report how some colleagues have completed such an experiment at Fermilab without finding anything untoward.

So where did Greenberg and Mohapatra go astray? Their starting point had been a modification of the algebra of the creation and annihilation operators, which they assumed to be feasible because it had been tried before. What they did not know was that a Soviet researcher, A.B. Govorkov from the international centre at Dubna, had shown as early as 1983 that the mathematical properties of the creation and annihilation operators forbid modifications other than those leading to the uninteresting states of parafermions and parabosons.

One virtue of this retraction is that the reasons why the argument went awry are fully explained, at least in language that those working in the field will readily understand. Another is the good humour of the piece, typified by the acknowledgement of Rudolf Haag "for having shown us the error of our ways". Yet another is the way that those who have helped to put the authors back on the straight and narrow path of rectitude are thanked for their help. And, finally, there are the grant-making agencies: support from the National Science Foundation is acknowledged in exactly the same terms in the two papers.

More than all this, the authors go on to give general reasons why their search for a basis on which Pauli's principle may be violated was a wild-goose chase from the start. The formalisms that give parabosons and parafermions correspond to the orthogonal and unitary symmetry groups of particular integral dimensions, but nobody has yet found a way in which these groups can be generalized into nonintegral dimensionality. It seems rather hard on the authors to suggest that their retraction should be taken as a model in this rare genre, but that is what it is.

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