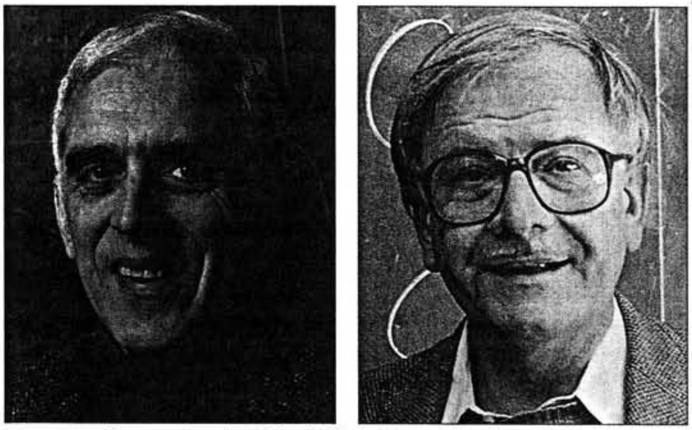
Anomaly leads to Dirac Medal

The 1998 Dirac Medal has been awarded to Stephen Adler and Roman Jackiw for their pioneering work on quantum field theory, writes **David Sutherland**



Dirac prizewinners – Stephen Adler (left) and Roman Jackiw

Field theory was the subject of much debate in the late 1960s. Quantum electrodynamics had proved to be a successful theory of the electromagnetic interactions between light and matter, but many physicists were sceptical about the use of field theory to describe strongly interacting particles. Two of the physicists who played a key role in showing that field theory could indeed be applied to the strong and weak interactions have been awarded the 1998 Dirac Medal of the International Centre for Theoretical Physics in Trieste, Italy. Stephen Adler of the Institute for Advanced Study at Princeton and Roman Jackiw of the Massachusetts Institute of Technology receive the medal for their "sophisticated use of quantum field theory to illuminate physical problems". The announcement was made on 8 August, Paul Dirac's birthday.

One of Adler's major contributions (and, independently, William Weisberger's) was the derivation of a sum rule for pion–nucleon scattering, which clarified the roles of currents and broken symmetries in the strong interaction. Jackiw's discovery (with Claudio Rebbi) of fractional charge and spin led to a major advance in the application of quantum field theory to condensed matter physics, and the fractional quantum Hall effect in particular. Their paths crossed when they made what may be their most important discovery: the celebrated triangle anomaly.

In the mid-1960s, inspired in large part by the success of Adler's sum rule, an algebra based on currents and the so-called PCAC (partial conservation of axial current) hypothesis had achieved considerable success in explaining various aspects of strong and weak interactions. Indeed, it appeared that this approach did not suffer from the complications that many physicists thought would arise when field theory was extended to the strong interaction.

However, there was a problem. The theory predicted that the neutral pion could not decay to two photons, but experiments showed that this decay was possible. It turned out, after careful analysis, that this discrepancy lay in the subtleties of field theory. Adler in one paper, and Jackiw and the late John Bell in another, showed that field theory contributed an extra term to the PCAC relation, which allowed the decay to occur. This term was proportional to the square of the charge of the fermion involved in the interaction and to the product of the electric and magnetic fields.

In addition to allowing the pion to decay, the extra term immediately produced an interesting new result. If the charged fermions in the interaction were fractionally charged quarks, the decay rate would still be an order of magnitude too small. If, however, quarks come in three colours, the decay amplitude would be three times as great, and the rate nine times as great, giving good agreement with experiment. This result gave strong support to earlier indications from baryon spectroscopy that quarks come in three colours.

The theoretical implications of this result are even more interesting. To see this, let us go back to the PCAC hypothesis. Without the Adler–Bell–Jackiw addition, the hypothesis states that the divergence of the axial current is proportional to the pion field, with the quark mass as the constant of proportionality. The up and down quarks have small but non-zero masses. If we suppose that these masses go to zero, we would have a conserved axial current. However, with the addition of quark effects, we find that this conservation law is violated and that a classical symmetry is violated. While it had been long realized that the transition from classical to quantum physics could be subtle, it was not expected that symmetries would be affected. As a result, this violation, and other similar violations discovered later, were termed anomalies.

A few years later, in 1971, the nascent Standard Model of particle physics received a boost when Gerhard t'Hooft proved that the Weinberg and Salam theory of the electroweak interaction was, in simple terms, self-consistent. However, it was realized that t'Hooft's proof would fail if an anomaly existed. Despite a number of interesting attempts, including some by Jackiw, to use anomalies as an alternative mechanism to break the symmetry of the electroweak interaction (and therefore give mass to particles), it is now generally accepted that anomalies should not be present in gauge theories. In fact, the cancellation of anomalies has now become a powerful constraint that has to be satisfied by any new gauge theory.

Anomalies also played an important part in the development of string theory. The discovery of an anomaly cancellation mechanism by Michael Green and John Schwarz in the early 1980s was a vital component in establishing superstring theories as viable contenders for theories that could unify all four fundamental interactions (i.e., gravity, electromagnetism and the strong and weak forces).

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Imaging prize

The 1998 Körber prize for European Science has been awarded to three physicists and a radiologist for their contribution to the development of magnetic resonance imaging (MRI) with hyperpolarized gases. The four winners are Ernst Otten of the University of Mainz in Germany, Werner Heil of the Institute Laue–Langevin in Grenoble, France, Michèle Leduc of the Ecole Normale Supérieure in Paris and Manfred Thelen of the Hospital for Radiology, also in Mainz.

The use of hyperpolarized gases makes it possible to image organs, such as the lung, that cannot be imaged using traditional MRI techniques. The method has its roots in atomic and nuclear physics research at Princeton University and the State University of New York at Stony Brook in the US. *Physics World* will publish a feature article on magnetic resonance imaging with hyperpolarized gases next month. The prize, worth DM 700 000 (£240 000), was presented in Hamburg last month.