

# Superstring fever

*The logo of the Symposium on Anomalies, Geometry and Topology, held at Argonne Laboratory and the University of Chicago in March.*

Mathematics and particle physics have often gone their separate ways in an attitude of mutual 'benign neglect', diverging in both methodology and language. This uncomfortable gap was bridged to a unique degree at the Argonne-Fermilab-Chicago symposium on Anomalies, Geometry and Topology, which took place at Argonne and the University of Chicago from 28-30 March, and which highlighted the new optimism in string, and particularly superstring, theories.

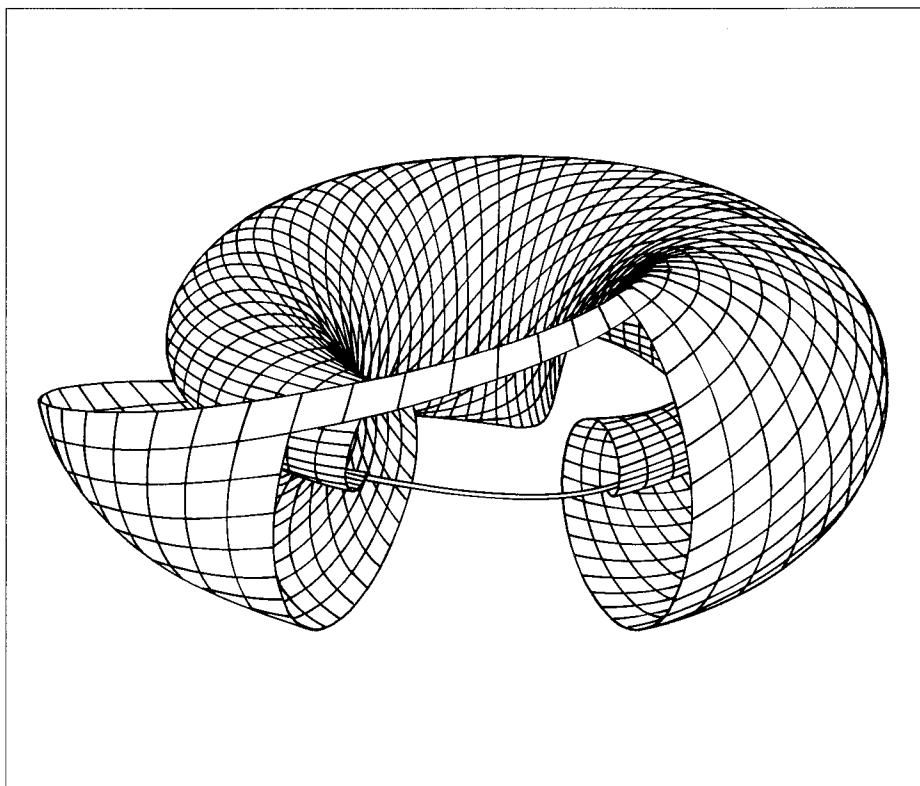
More than 300 theoretical physicists and mathematicians met together to discuss problems of current excitement and to report

## Superstrings

*As their name suggests, mathematical strings are extended objects, rather than points.*

*Supersymmetry is the new idea of pairing particles with supersymmetric partners.*

*The known fundamental particles are conventionally divided into two kinds. First there are the fermions (quarks, electrons, etc.) which make up matter. Then there are the bosons (photons, gluons, Ws and Zs) which carry the forces between the particles. Supersymmetry says that each matter fermion must have a supersymmetric counterpart boson, and vice versa. Superstrings are the supersymmetric partners of conventional strings, and have ten dimensions. These ten dimensions then have to be collapsed down to four by 'compactification'.*



on recent progress in an atmosphere of remarkably unguarded optimism. In an overview, John Schwarz of Caltech described how superstring theories are now making dramatic strides towards achieving the ultimate goal of a unified quantum theory of all interactions including gravity.

Of course, superstrings are not isolated theoretical constructs but sit naturally at the peak of a large pyramid of theoretical concepts developed during the past few years, none seeming to be the whole truth but each having elements of formal beauty and aspects of physical reality. Several speakers at the Symposium expressed the opinion that with the arrival of superstrings, winning the theoretical jackpot is no longer a dream.

A unifying theme of the Symposium was the mathematical disci-

pline of topology, which has intrigued particle theorists for a long time. However in the last few years the general relevance of topology to the understanding and computation of so-called 'anomalies' has become much more apparent. Anomalies are subtle violations in the fundamental symmetries used to build the gauge field theories describing the forces of Nature. Arranging for these anomalies to cancel is important in quantum field theories. However anomalies have much broader implications. Most recently they have played a crucial role in developing the new versions of the quantum string model. The mathematical structure of anomalies and the new developments in superstring theories dominated discussions at the Symposium.

Anomalies were discovered 'long ago' by Jack Steinberger when he

*Mathematician I. Singer delivers his plenary talk. The Symposium succeeded in getting mathematicians and physicists to talk the same language.*

was trying to calculate the decay of the neutral pion into two photons, using the limited theoretical repertoire available at the time. Anomalies have since proceeded from protons to quarks to strings. Relatively simple calculations have led to precise theorems concerning fundamental physical processes. The original mathematical focus of anomalies concerned properties of Dirac (half-integer spin) operators and the related index ('handedness') theorems discovered by mathematicians M.F. Atiyah and M. Singer.

Very recently it has become possible to study anomalies using these powerful topological techniques. As a result, anomalies have been computed outside (as in Ed Witten's discrete gauge anomaly) the straitjacket of perturbation theory which for so long has hampered field theory; a variety of anomalies in different space-time dimensions were correlated using elegant differential geometry constructions; and several new ones, including the gravitational anomalies (the nonconservation of the energy-momentum tensor) were derived in a general context. This last development in turn proved crucial in computing a subtle gauge-gravitational anomaly cancellation in the intriguing superstring theory of J. Schwarz and M. Green. This recently discovered cancellation opened the door to the dramatic developments and intense activity which led to the new results reported at the Symposium.

While the Symposium concentrated on superstrings, there were also many other highlights. The intense level of interaction between mathematicians and physicists was certainly a notable feature. Atiyah remarked 'I used to think mathe-



maticians and physicists were very different. Physicists were interested in four dimensions only and never in unusual cases while mathematicians were always interested in general numbers of dimensions and the unusual cases'. He noted that three branches of mathematics — index theorems, complex manifolds, and Kac-Moody algebras — are all playing a role in current string theory. He also traced the history of anomalies in relation to the index theorems, and gave a general discussion of mathematical ideas (spectral flow) needed for the new physics applications.

A major focus of the Symposium was the mathematical structure of anomalies, which provided an interesting point-counterpoint between physicists and mathematicians.

Ed Witten presented an analysis of global (rather than local) anoma-

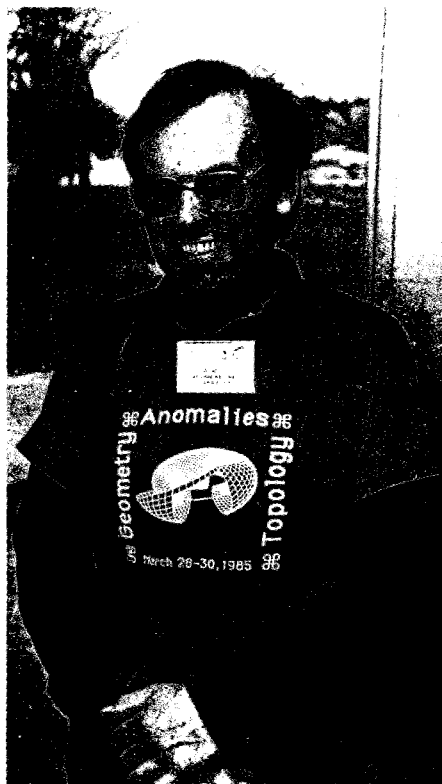
lies which could provide additional restrictions on the theories. He showed that these do not apply to the superstring theory but may be important for the 'compactification' of the extra dimensions of the theory. Roman Jackiw summarized topological aspects of anomalies in defining quantum gauge field theories.

J.R. Schrieffer provided the condensed-matter physicist's viewpoint, and reported on some examples (such as the solitons of polyacetylene or the fractional charges of the quantum Hall effect) which are actually observed. His talk showed that here indeed was real physics. (Fractional charges are a characteristic fingerprint of anomalies).

In a somewhat different vein, Gerard 't Hooft presented his work on black holes and argued that a new physical picture of the 'inter-

Organizers Bill Bardeen (Fermilab) left, and Alan White (Argonne) resplendent in Symposium tee-shirts. Also on the organizing committee were P. Freund and Y. Nambu of Chicago and E. Braaten of Northwestern University.

(Photos Argonne)



ior' of a black hole may be necessary for a consistent interpretation of Hawking radiation. He also took on the role of devil's advocate in the evening panel discussion by posing the questions asked by the 'average' physicist when first exposed to string ideas.

This Symposium may well be remembered as the first meeting where superstring physics emerged as a theme for the entire physics community. Like many other successful theories, strings started on the wrong track. The electroweak gauge theory, for example, stemmed from the monumental efforts of Yang and Mills who some twelve years previously had tried to develop a formalism for strong interactions.

String theories were formulated in 1970 by Y. Nambu and others as an elegant codification of the dual resonance structure of the

strong interaction mechanism. Other attempts followed, but it soon became clear that the fundamental string theory could not be regarded as a satisfactory model of strong interactions.

To compress unwanted dimensions, the work of Kaluza and Klein, carried out 65 years ago, was resurrected. Then supersymmetry appeared on the scene (see the article by Bruno Zumino in the January/February 1983 issue, page 18). But strings languished in the wilderness. They seemed to be without physical applications.

In 1974, J. Scherk and John Schwarz decided to apply strings to a totally different problem, the quantum theory of gravity. The relativistic string contained a massless, spin two excitation which was no good for strong interactions but could be identified as the graviton, the quantum of the grav-

itational field. The simplest terms for calculating the scattering of this massless quantum were shown to agree with those derived from Einstein's theory of gravity.

In 1976, F. Gliozzi, Scherk and D. Olive realized that fermionic strings could produce a supersymmetric theory in ten dimensional space-time. Superstrings were born. Their properties suggested that superstring theory might succeed where field theory had failed. A complete string theory is now envisaged as including all interactions of the universe — seen and unseen.

The breakthrough achieved in superstring theory and the impact of the Symposium can perhaps be summarized by the following comments. Mike Green remarked 'I feel the symmetry groups found for the superstring are very important but I am not yet convinced that one particular superstring theory is correct'. Ed Witten commented 'this was the first widely attended conference since the (superstring) revolution. Before this meeting the significance of the developments had not really sunk in for many people'. David Gross expressed the greatest optimism and said 'it is remarkable how easily recognizable features of physics emerge from superstrings. While I don't believe we have yet found the right route, there appear to be no insuperable obstacles to deriving all known physics from the  $E_8 \times E_8$  heterotic string'.

*From A.R. White and C.K. Zachos, Argonne, and W.A. Bardeen, Fermilab.*