International Atomic Energy Agency

United Nations Educational, Scientific and Cultural Organization

International Centre for Theoretical Physics

News from ICTP

No. 36/37
July/August 1990

Contents

Fields Medal to E. Witten 14

Copley Medal to Abdus Salam

The Council of the Royal Society has awarded the Copley Medal 1990 to Professor Abdus Salam, K.B.E., F.R.S., in recognition of his work on the symmetries of the laws of nature, and especially the unification of the electromagnetic and weak forces.

Professor Salam has made outstanding and influential contributions to elementary particle theory over a period of 40 years. His early work included the completion of Dyson's proof of the renormalization of Quantum Electrodynamics, and his work on parity violation, dispersion relations and SU(3) invariance. This work contributed greatly to the development of elementary particle theory, but his major contribution was the proposal, in parallel with S. Weinberg, of the electroweak theory, unifying Quantum Electrodynamics with the weak interactions between atomic particles. That theory, the first to bring together

interactions between atomic particles. That theory, the first to bring together

the theories of the atomic forces, received spectacular confirmation through the discovery at CERN in 1983 of the W± and Z° intermediate bosons.

A Portrait of a Friend: Stig Lundqvist

by Hilda Cerdeira

Stig Lundqvist is well known at the ICTP for his scientific and organizational competence and for his warm personality. In this paper, Hilda Cerdeira discloses quite unknown traits of Stig which make him an even more fascinating person. A message from H. Blix, Director General of the International Atomic Energy Agency, which was read on the occasion of the Symposium, is also presented.

Professor Stig Lundqvist, Chairman of the Scientific Council of the ICTP, turned 65 on August 9th. His friends prepared a short, high-quality meeting in his honour, under the title "Symposium on Frontiers in Condensed Matter Physics in honour of Prof. Stig Lundqvist."

During a long chat that, I could say, has extended through years, I have come to know partly this man, whose work was acknowledged with this event.

In a nutshell, his life can be summarized as follows: he was born in Gudmudrå, in Northern Sweden, studied at the University of Uppsala, got married during his student years in 1949, became an assistant professor at Uppsala after getting his Ph.D. He moved to the University of Gothenburg in 1961, as an assistant professor, and became full

University of Gothenburg in 1961, as an assistant professor, and became full

professor in 1963. He started to work with the Nobel Committee in 1972, which he left officially in 1985, to be appointed as the Chairman of the Physics Class of the Swedish Academy of Sciences. He has been the Chairman of the Scientific Council of the ICTP since 1985.

He comes from a a family with high appreciation for music and reading. A Christmas morning concert in his hometown, played with an organ, inspired him at an early age to start playing it, disturbing not only his family but also his classmates. From his father he got a special ability to build

Abdus Salam congratulates Stig Lundqvist for his birthday and for his accomplishments. On the left, the Rector of Chalmers University of Technology, Prof. A. Sjöberg.

things, and as many children of his own age, built model planes that did not work. But, where most children stop, he kept inquiring the reasons of failure. Whether this was the beginning of his liking of physics is hard to tell, but his interest in physics and music moved him through his adolescence.

He started a jazz band at the age of 14, which lasted for a year. After that he moved on to play with professional bands. This helped him to keep his then hobby of physics, since a good part of his income was spent in physics and mathematics books. He played jazz with people like Stan Haselgård, who later became famous as a clarinet in Benny Goodman's band and later on in Goodman's band, and later on in California when he was visiting as a scientist, with Bud Shanks, where he used to give Sunday concerts.

At the age of 21 after his military service, he entered the University of Uppsala. At that time, most Swedish universities were not prepared to receive students who did not belong to academic families. And it was a shock to find this Laplander, son of nobody, to make it by sheer stubborness. The University teaching was poor at the time due to the archaic structure. Stig made a lot of efforts to change the stiffness of education in Swedish universities. He became an assistant professor at the University of Uppsala in 1955. There he started to get interested in many body theory, and helped by Jerry Brown, from Copenhagen, who visited Uppsala frequently, he went for a semester to the Niels Bohr NORDITA Institute, where he could feel the excitement of the Niels Bohr years. In 1958, he went to the USA to work with Keith Brueckner, and made some acquaintances that are nowadays some of his best friends.

He became aware of the ICTP when it was only a dream of Abdus Salam, in the early sixties. He got involved in the Condensed Matter program from the beginning. After the first course in this subject which was held in 1967 and had been organized by J. Ziman, F. Bassani and himself, he started in 1970 the Summer Workshops with the help of Paul Butcher, Federico Garcia Moliner and Norman March. He has made an effort to present always high quality activities at the ICTP, always bringing what of new and interesting is around. He has also tried to make the Centre a place of high quality research. It is in this area that now, at retirement age, where most people would be thinking of receding into a quiet life, that he is planning to put his efforts by spending most of his time here.

Two years ago his friends and colleagues Elias Burstein, Praveen Chaudhari, Robert Schrieffer, Erio Tosatti and Yu Lu started to organize a conference to celebrate his 65th birthday.

The conference (or birthday party) lasted three days and it was attended by many of his friends and close acquaintances, five Nobel laureates — P.W. Anderson, K. von Klitzing, H. Rohrer, Abdus Salam and R. Schrieffer — his children and grandchildren, ex-students and many well known

From left to right: R. Schrieffer, P.W. Anderson, Abdus Salam, S. Lundqvist and P. Budinich. Standing behind Profs. Lundqvist and Budinich are E. Burstein and H. Rohrer.

physicists who made the conference a very successful event.

In his own words the most striking fact of the conference was the "tremendous enthusiasm and momentum going on in the frontiers of condensed matter physics, whose borders are becoming loose with time. Condensed matter extends now from atomic and molecule problems to theory of complexity or that of computation (as presented by B.A. Huberman). Progress in condensed matter is no longer restricted to natural materials but to man-made devices in semiconductors, covering wide areas of physics of today as shown by H. Stormer".

Prof. P. Chaudhari lecturing at the Symposium.

During the ceremony Stig was presented with the Chalmers Medal by the Rector of Chalmers University, Prof. Anders Sjöberg, and with the Dirac Medal of the ICTP by Prof. Abdus Salam.

Message from the Director General of IAEA

Dear participants,
Dear Stig,

With much regret, I had to decline the invitation to participate with you in the Symposium on Frontiers in Condensed Matter Physics dedicated to the 65th anniversary of Stig Lundqvist.

Many know of Stig's impressive achievements in the Swedish academic scene, but I believe too little is known about his involvement in the international scientific world and in the International Centre for Theoretical Physics in particular. This involvement has been exemplary; Stig was one of the Directors of the College on Condensed Matter in October-December 1967. This first course was to have a great significance in the scientific history of the Centre because it introduced a new important discipline in the curriculum of the Centre in addition to elementary particle, nuclear and plasma physics, and a branch which was also relevant to the interests of the IAEA. It is Stig's great merit that all potentialities of this branch of human knowledge are now made available to the scientists and engineers in the developing countries. From the early seventies onwards, Stig and a team of distinguished colleagues — Profs. N. March, P.N. Butcher, F. García-Moliner and others — started to consolidate the programme in condensed matter physics. In a first phase and in a series of high-level courses, he patiently trained many young physicists from the Third World and gave them an opportunity to exercise their creativity in research workshops which became a regular feature of the programme. Later, he persuaded Italian colleagues to help in setting up a permanent research group at the Centre. This group is nowadays known as one of the best in the world.

Stig Lundqvist is a convinced internationalist and wishes to offer the very best to those who come to work to Trieste. In 1986 he created the Adriatico Research Conferences — five to seven conferences every year — where he invites the most eminent scientists both from developing and from advanced countries and where anyone who is genuinely interested can learn about the latest developments in a large variety of topics.

Stig Lundqvist's commitment to the growth of science in the developing countries was the reason he was called to serve on the Scientific Council of the ICTP (1982) and as its Chairman since 1984. On many occasions, I admired his sharp vision on the role of the ICTP and the wisdom of his advice. For all these accomplishments, we in the IAEA are most grateful to you, Stig. We hope to count on your invaluable advice for the future.

I wish you a happy birthday amidst your friends and colleagues.

To the participants, I wish a very fruitful conference around Stig who has done so much for the success of your discipline.

Honorary Degree to Abdus Salam

On Thursday 12 July, Professor Abdus Salam, Director of the International Centre for Theoretical Physics and President of the Third World Academy of Sciences, was honoured with the diploma of Doctor of Science Honoris Causa of the University of Ghana. As Abdus Salam could not travel to Ghana, the ceremony took place in the Main Lecture Hall of the ICTP. The Vice-Chancellor of the University of Ghana, Prof. A. Sawyerr, wearing the gown of his University, accompanied by His Excellency the Ambassador of Ghana to Italy, Mr. G. Lamptey, and a delegation of Ghanaian personalities were the guests of the ICTP for the whole day. The Vice-Chancellor read the citation for the degree:

"Abdus Salam, born in Jhang, Pakistan, on January 29, 1925, you were at birth given the name you still bear, which means "Servant of Peace". You have indeed lived up to your name. In 1968, the Atoms for Peace Foundation saw fit to award you the "Atoms for Peace Medal", which is only one in a long string of awards attesting to a lifetime in the pursuit of peace.

"You gave early notice of academic excellence when at he age of 14 you scored the highest marks ever recorded at a Matriculation Examination in Pakistan. This was followed by scholarships to Government College at Jhang, Punjab University in Lahore, and St. John's College, Cambridge, in a continuing manifestation of academic excellence.

"You have undertaken a variety of assignments as a teacher and researcher, and as consultant and adviser to governments and international bodies, including the United Nations. You have written books and published a host of papers, many of which have received

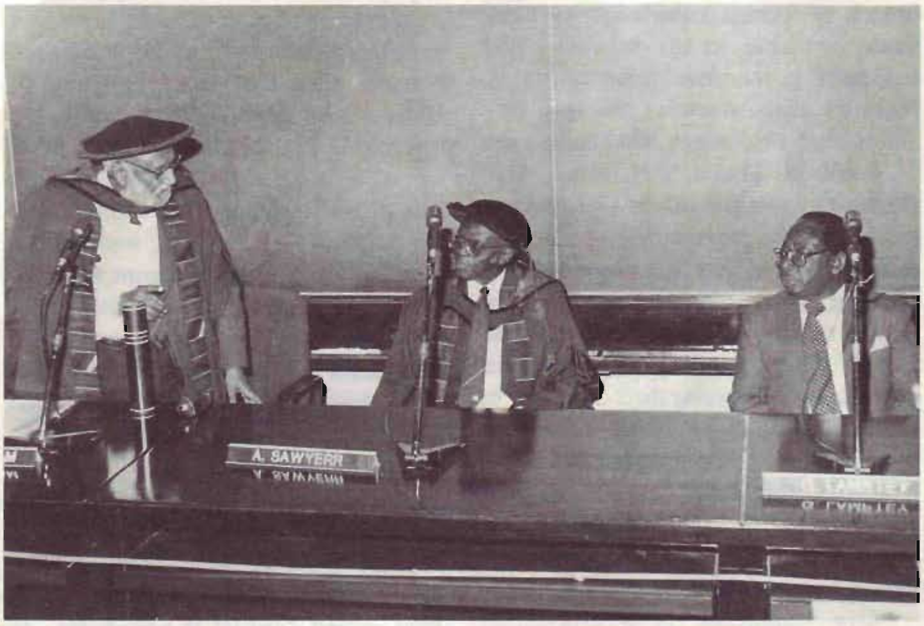
worldwide acclaim. You have been appointed to Professorships; elected to Fellowships of Learned Academies and Societies; admitted to Distinguished Orders; and awarded prizes and other symbols in recognition of your outstanding attainments. All of this culminated in the award to you in 1979 of the Nobel Prize for Physics.

"For us in the Third World, you hold a special place as much for these achievements as for your continuing efforts at improving the conditions for the study of science in our deprived environment.

developing countries with what they need to sustain and develop their competence as scientists, and enhance their contribution to the well-being of their peoples.

"Nor is that all. In 1984 you, in concert with others, founded the Third World Academy of Sciences to continue the propagation of science on a still broader front, with the aim of bringing the more advanced aspects of science closer to the hitherto less scientifically developed countries of the world.

"In all this, you have given of yourself totally and without counting the



Abdus Salam, the Vice-Chancellor of the University of Ghana A. Sawyerr and H.E. the Ambassador of Ghana to Italy Mr. G. Lamptey, at the Honorary Degree Ceremony.

"The International Centre for Theoretical Physics at Trieste, your *brainchild, which continues to flourish* *Theoretical Physics at Trieste, your brainchild, which continues to flourish under your direction, has played host to many a Third World scientist, who subsequently achieved distinction in science and public service. Here at the Centre, short-term concentrated courses on advanced topics in physics are available, at little or no cost, to all who care to, and are able to, take advantage of them. This Centre has exposed physicists from the developing countries to each other, to physicists of the developed countries, and to the latest developments in a rapidly changing subject area. Thus has the Centre, under your inspired and inspiring leadership, continued to equip scientists of the*

cost, for the upliftment of mankind.

"For your services to mankind many cost, for the upliftment of mankind.

"For your services to mankind many well-deserved honours have been bestowed on you already. Beginning in 1957, you have received honorary Doctor of Science degrees on more than 30 different occasions from Universities the world over. We are proud today to be counted among those institutions which have had the privilege of honouring you.

"Abdus Salam, true Messenger of Peace, teacher, researcher and humanist, for your academic achievements, your personal contribution to scientific research, your selfless and extraordinary devotion to the promotion of science throughout the world for peaceful purposes, and your insistence on the participation of Third World countries in the study, and development and application of science, the University of Ghana is proud to honour you. I feel truly honoured to invite you to step forward to receive the degree of Doctor of Science, Honoris Causa, of the University of Ghana, Legon."

After receiving the diploma from the hands of the Vice-Chancellor, Abdus Salam also wearing the gown of the University of Ghana, expressed his gratitude for the distinction bestowed on him and briefly recounted his reminiscences of his early and later acquaintance with the Ghanaian scientific reality.

A.M. Hamende

Dirac Medals 1990

The 1990 Dirac Medals of the International Centre for Theoretical Physics (ICTP), Trieste (Italy), have been awarded to Prof. Ludwig Dmitriyevich Faddeev (Steklov Mathematical Institute, Leningrad, USSR) and Sidney Richard Coleman (Harvard University, Cambridge, Massachusetts, USA).

Ludwig Dmitriyevich Faddeev is honoured for researches in the area of quantum field theory and mathematical physics. His name is well known in theoretical physics in connection with the Three Body System (Faddeev' equation). He made decisive contributions to the quantization of the Yang-Mills and gravitational field. The Faddeev-Popov covariant prescription of quantization of non-Abelian gauge Faddeev-Popov covariant prescription of quantization of non-Abelian gauge theories discovered in 1966-67 has many essential applications including quantum effects in the Glashow-Salam-Weinberg model of electroweak interactions and in quantum chromodynamics. Faddeev is a disciple of Dirac's ideas in theoretical physics. His studies are related with the evolution of the Dirac Hamiltonian interpretation in the inverse scattering method (1971) and with exact integrable systems, as well as with quantum theory of solitons (1975). He also clarified the group-theoretical origin of anomalies in the context of cocycles (1984). His works stimulated the wide-spread application of solitons in relativistic quantum field theory. Faddeev's contributions to the quantum inverse scattering method and 4-matrix theory initiated the development of this direction which is now known as the Quantum Group Approach. His scientific work significantly contributed to the broad extent of geometrical and algebraic ideas in modern theoretical and mathematical physics.

Prof. Ludwig Dmitriyevich Faddeev was born in Leningrad on March 23, 1934. He graduated from Leningrad State University in 1956. He received his Ph.D. in 1956 and degree of doctor of sciences in 1963 at Steklov Mathematical Institute of the USSR Academy of Sciences. Prof. Faddeev permanently works at Leningrad Department of Steklov Mathematical Institute. He started as a Research Associate (1960), Senior Research Associate (1964), then became leader of the Laboratory of Mathematical Methods of Physics (1974) and Deputy Director for the Leningrad Department of Steklov Institute in 1976. He was appointed as Professor at the Department of Mathematical and Mathematical Physics in 1967. Ludwig D. Faddeev is a Member of the USSR Academy of Sciences (1976), Member of the American Academy of Science and Art at Boston (1979), President of the International Union of Mathematics (1986), Honorary Member of the Academy of Science of Poland (1987), Doctor Honoris Causa of Universities at Nankai and Buenos Aires (1987 and 1988), Foreign Member of the Academy of Science and Literature of Finland (1988). He has published more than 150

of Science and Literature of Finland (1988). He has published more than 150

scientific articles and five books. He is a member of the editorial board of several international journals. Honours bestowed include: USSR State Prize (1971) and Danny Heinemann Prize on Mathematical Physics (1975).

Sidney Richard Coleman is honoured for his contributions to quantum field theory and particle physics. His work on quantum field theories has greatly clarified their structure. This includes the classification of all possible bosonic symmetries of S-matrix (with J. Mandula) and the study of some fundamental properties of two-dimensional quantum field theories, including, in particular, the absence of symmetry breaking and aspects of boson-fermion equivalence. His study (with E. Weinberg) of the quantum effective action and the phenomenon of dimensional transmutation has had an important influence on the development of the subject. Sidney Coleman's work on global aspects of quantum field theories has also been of fundamental importance in the development of the subject. This includes his work on the fate of false vacuum, on the discovery of Q-balls, and more recently, on the potentially far-reaching physical consequences of wormholes. These contributions are paralleled by the equally important one of teaching the younger generation of particle physicists the modern concepts in quantum field theories through very lucid lectures and papers.

Prof. Coleman was born on 7 March 1937 in Chicago, Illinois, USA. He obtained his B.Sc. at the Illinois Institute of Technology in 1957 ad his Ph.D. at the California Institute of Technology in 1962. He started his career at Harvard University as a Corning Lecturer on and Research Fellow in physics (1961-63). He then became Assistant Professor of Physics (1963-65), Alfred Sloan Fellow (1964-65), and Associate Professor of Physics from 1966 to 1968 at the same University. After spending one year at the University of Rome, Italy, as a Visiting Professor, he returned to Harvard where he was appointed as a Professor of Physics in 1969. He was visiting Professor one year at Princeton in 1973 and at Stanford in 1979-80. In 1980, he was appointed

year at Princeton in 1973 and at Stanford in 1979-80. In 1980, he was appointed

as a Donner Professor of Science at Harvard University. In 1989 he was again visiting Professor at Berkeley. Honors bestowed include the Boris Pregel Award from the New York Academy of Sciences; the Award for Lectures in Physics from the Centro Ettore Majorana (International School of Physics, Erice, Italy); J. Murray Lack Award for Scientific Reviewing given by the National Academy of Sciences; and the Distinguished Alumnus Award from the California Institute of Technology. Prof. Coleman is a Fellow of the American Physical Society, American Academy of Arts and Sciences and National Academy of Sciences. He is the author of 82 papers.

— • —

The Dirac Medals of the International Centre for Theoretical Physics were instituted in 1985 in memory of Prof. P.A.M. Dirac, an honoured guest and staunch friend of the ICTP. They are awarded every year on Dirac's birthday – 8 August – for contributions to theoretical physics. From 1990, the Medalists will also receive a US$ 10,000 cheque.

In 1985, the Dirac Medals were awarded to Professor Yakov Zeldovich (Institute for Space Research, Moscow, USSR) and Prof. Edward Witten (Princeton University, USA), and in 1986 to Prof. Yoichiro Nambu (Enrico Fermi Institute for Nuclear Studies, Chicago University, USA) and Prof. Alexander Polyakov (Landau Institute for Theoretical Physics, Moscow, USSR). In 1987, they were awarded to Prof. Bryce DeWitt (University of Texas at Austin, USA) and Prof. Bruno Zumino (University of California at Berkeley, USA). The recipients of the 1988 Medals were Prof. David J. Gross (Princeton University, USA) and Prof. Efim S. Fradkin (Lebedev Physical Institute, Moscow, USSR). In 1989, the Medals were awarded to John H. Schwarz (Caltech, Pasadena, USA) and Michael B. Green (Queen Mary College, London, UK).

The Selection Committee includes Professors S. Lundqvist, R. Marshak, J. Schwinger, S. Weinberg, E. Witten, Abdus Salam and others. The Dirac Medals of the ICTP are not awarded to Nobel Laureates or Wolf Foundation

Medals of the ICTP are not awarded to Nobel Laureates or Wolf Foundation

Prize winners.

Dirac Medal Award Ceremony

On July 4, J.H. Schwarz (Caltech, Pasadena, USA) received the 1989 Dirac Medal which had been awarded to him last year. The other of the two Medals awarded every year on the birthday of P.A.M. Dirac — 8th August — went to Michael Green from Queen Mary College, London, UK.

The ceremony took place in the Main Lecture Hall of the ICTP. After an introduction to the work of J.H. Schwarz by Professor Abdus Salam, Director of the ICTP, Prof. P. Fasella, a biochemist and Director General of the European Economic Community's General Directorate for Science, Research and Development, read the citation and presented the Medal to the awardee. He added:

"I wish to say what a strong importance we attribute to basic sciences not only as the source of the knowledge and know-how which we need to solve our socio-economic problems but also as a venture of mankind itself.

"It is a great honour to be associated with the presentation of this very important prize and I am very grateful to you, Professor Salam, and to the International Centre. And, as you say, we are extremely interested in what we do. We have started some collaboration and look forward for more in the future."

Immediately after, J.H. Schwarz lectured on *"String Theory — Some Reminiscences"*.

A.M. Hamende

Dirac Medal winner J.H. Schwarz and Abdus Salam.

String Theory — Some Reminiscences

by J.H. Schwarz

I have decided to use the occasion of receiving this wonderful honor — the Dirac Medal — to recall some of the highlights of 'my life as a string theorist.' String theory has a rather complex and bizarre history, so it is not possible for me to present a complete and balanced treatment. Instead, I have decided to focus on four specific episodes in which I have been directly involved: supersymmetry on the world sheet, strings

for unification. space-time supersymmetry in string theory. and
directly involved: supersymmetry on the world sheet, strings

for unification, space-time supersymmetry in string theory, and the 1984 superstring revolution. The history of string theory prior to 1971 is a fascinating story that I will completely omit.

Supersymmetry on the World Sheet

The Veneziano string theory (or 'dual model'), developed in the period 1968-70, suffered from several unphysical features: the absence of fermions, the presence of a tachyon, and the need for 26-dimensional space-time. These facts motivated the search for a more realistic string theory. The first significant success was made in January 1971 by Pierre Ramond,[1] who had the inspiration of constructing a string analog of the Dirac equation.

A bosonic string $X^\mu(\sigma, \tau)$ with $0 \le \sigma \le 2\pi$ has a momentum density $P^\mu(\sigma, \tau) = \frac{\partial}{\partial\tau} X^\mu(\sigma, \tau)$, whose zero mode

$$p^\mu = \frac{1}{2\pi} \int_0^{2\pi} P^\mu(\sigma, \tau)\, d\sigma \qquad (1)$$

is the total momentum of the string. Ramond suggested introducing an analogous density $\Gamma^\mu(\sigma, \tau)$, whose zero mode

$$\gamma^\mu = \frac{1}{2\pi} \int_0^{2\pi} \Gamma^\mu(\sigma, \tau)\, d\sigma \qquad (2)$$

is the usual Dirac matrix. He then defined Fourier modes of the product $\Gamma \cdot P$

$$F_n = \frac{1}{2\pi} \int_0^{2\pi} e^{-in\sigma} \Gamma \cdot P\, d\sigma. \qquad (3)$$

The zero mode,

The zero mode,

$$F_0 = \gamma \cdot p + \text{oscillator terms} \qquad (4)$$

is an obvious generalization of the Dirac operator, suggesting a wave equation of the form

$$F_0 = |\psi\rangle = 0 \qquad (5)$$

for a free fermionic string.

By postulating the usual commutation relations for X^μ and P^μ as well as

$$\{\Gamma^\mu(\sigma, \tau), \Gamma^\nu(\sigma', \tau)\} = 4\pi\eta^{\mu\nu}\delta(\sigma - \sigma'), \qquad (6)$$

he discovered the 'super-Virasoro' or '$N=1$ superconformal' algebra

$$\{F_m, F_n\} = 2L_{m+n} + \frac{c}{3}\left(m^2 - \frac{1}{4}\right)\delta_{m+n,0}$$

$$[L_m, F_n] = \left(\frac{m}{2} - n\right) F_{m+n} \qquad (7)$$

$$[L_m, L_n] = (m - n)L_{m+n} + \frac{c}{12}(m^3 - m)\,\delta_{m+n,0},$$

generalizing the well-known Virasoro algebra (given by the

L_n's alone).

While Ramond was doing the work described above, André Neveu and I were working together at Princeton on the development of a new interacting bosonic string theory containing a fermionic world-sheet field $H^\mu(\sigma, \tau)$ satisfying the same anticommutation relations as $\Gamma^\mu(\sigma, \tau)$, but antiperiodic in σ.[2] H^μ therefore has half-integral Fourier modes (b^μ_r), $r \in Z + 1/2)$ only. The same super-Virasoro algebra arises, but with half-integrally moded operators

$$G_r = \frac{1}{2\pi}\int_0^{2\pi} e^{-ir\sigma} H \cdot P \, d\sigma \qquad (8)$$

replacing the F_n's. We thought that our theory came quite close to giving a realistic description of nonstrange mesons, so we called it the 'dual pion model.' Nowadays, my viewpoint is quite different, of course. In any case it was clear to me already in 1971 that there is a very rich mathematical structure that needs to be understood irrespective of any possible physical interpretation.

Together with Charles Thorn, we figured out how the G_r operators acted as subsidiary gauge conditions in the interacting theory.[3] The key step was to redefine the vacuum by a 'picture-changing' operator. We called the original string Fock space F_1 and the new one F_2. Only in the F_2 picture were the super-Virasoro conditions realized in a straightforward way. At the same time we began to appreciate the formal similarity between our construction and the work of Ramond. This led us to conjecture that our model could be extended to include Ramond's fermions. Neveu and I succeeded in finding a vertex operator describing the emission of a 'pion' from a fermionic string. We used it to construct amplitudes for two fermions and any number of pions.[4] Two weeks later Charles Thorn presented a paper containing the same results[5] as well as the first explicit formulas for fermion emission.

Let me now turn to the question of what all this has to do with supersymmetry. First of all, it is now understood that the Virasoro algebra describes two-dimensional conformal transformations, which can be regarded as analytic mappings of a Riemann surface. The infinitesimal generator $L_n \sim -z^{n+1}\frac{d}{dz}$ corresponds to $z \to z + \varepsilon z^{n+1}$. The super-Virasoro (or

superconformal) algebra can be regarded as a generalization to
corresponds to $z \to z + \varepsilon z^{n+1}$. The super-Virasoro (or

superconformal) algebra can be regarded as a generalization to 'super-analytic' mappings of a 'super Riemann surface,' with local coordinates z and θ, where θ is a Grassmann number.

Later in 1971, Gervais and Sakita proposed an interpretation in terms of a two-dimensional world-sheet action principle.[6] Specifically, they described the $X^\mu(\sigma, \tau)$ as free scalars (this was known previously) in supersymmetry multiplets with free Majorana (2-component) fermions $\psi^\mu(\sigma, \tau)$. The action is

$$S = \frac{1}{2\pi}\int d\sigma\, d\tau \{\partial_\alpha X^\mu \partial^\alpha X_\mu - i\, \overline{\psi}^\mu \rho^\alpha \partial_\alpha \psi_\mu\} \qquad (9)$$

where ∂_α are world-sheet derivatives $\left(\frac{\partial}{\partial\tau}, \frac{\partial}{\partial\sigma}\right)$ and ρ^α are two-dimensional Dirac matrices. They noted that this action S is invariant under the global supersymmetry transformation

$$\delta X^\mu = \overline{\varepsilon}\, \psi^\mu$$
$$\delta \psi^\mu = i\rho^\alpha \varepsilon \partial_\alpha X^\mu, \qquad (10)$$

where ε is a constant infinitesimal Majorana spinor.

When ψ^μ has periodic boundary conditions (and hence integrally-labeled Fourier modes) it corresponds to Ramond's $\Gamma^\mu(\sigma, \tau)$. When it is taken to be antiperiodic, it corresponds to $H^\mu(\sigma, \tau)$. Since X^μ is ordinarily periodic, the global symmetry described above only applies to the Ramond sector. The operators F_n or G_r correspond to Fourier modes of the associated Noether current, just as L_n corresponds to modes of the two-dimensional energy-momentum tensor.

A deeper understanding of the significance of the super-Virasoro gauge conditions became possible following the development of supergravity.[7] That theory involved making space-time supersymmetry local, so it was natural to attempt the same for world-sheet supersymmetry. This was achieved by introducing a two-dimensional 'zweibein' field e^a_α that describes the geometry of the world sheet and a Rarita-Schwinger field χ_α, which is a gauge field for world-sheet supersymmetry.[8]

The discovery of this action was important for several reasons. First, it exhibits a local Weyl symmetry, a feature that depends crucially on the two-dimensionality of the world sheet. There is also an associated local fermionic symmetry. The local symmetries are just sufficient to choose a gauge in which $e^a_\alpha = \delta^a_\alpha$ and $\chi_\alpha = 0$ in local coordinate patches. (In general, there are topological obstructions to doing this globally on the world sheet.) In this gauge the X^μ and ψ^μ equations of motion are simply $\partial^\alpha\partial_\alpha X^\mu = 0$ and $\rho^\alpha\partial_\alpha\psi^\mu = 0$, a free wave equation and a free Dirac equation, for which the general solution is easily written down. Also, the χ_α and e^a_α equations of motion become the vanishing of the supercurrent and the energy-momentum tensor. This provides a logical foundation for the super-Virasoro gauge conditions.

A second reason that this formalism proved to be important is the crucial role it plays in Polyakov's 1981 formulation of string amplitudes as a sum over conformally inequivalent world-sheet geometries.[9] Since this viewpoint is so fundamental, many people now refer to S (whether for bosonic or fermionic strings) as the 'Polyakov action.'

or fermionic strings) as the 'Polyakov action.'

Strings for Unification

String theory was originally developed (by a bizarre sequence of serendipitous events) out of the S matrix program for understanding the strong interactions. The physical picture that emerged was one in which hadrons could be pictured as strings, about a fermi in length, with quarks attached to the ends. There was a period of considerable optimism about the prospects for formulating a complete theory of hadrons in such terms. This program achieved a number of qualitative successes because string theory amplitudes incorporate several general features originally identified as properties of hadrons such as Regge behavior and duality.

After a period of about five years of intense development (1968-73) it became clear to most theorists working on string theory that there were severe, perhaps insuperable, difficulties. Some of these were the need for extra dimensions, the appearance of tachyons and massless particles, and the inability to account for the point-like structure revealed in deep inelastic scattering experiments. The final nail was driven into the coffin of string theory when QCD emerged as a successful theory of the strong nuclear force. String theory was abandoned by almost everyone even more quickly than it had arisen.

A few theorists (such as Polyakov, Gervais, Neveu,...) continued to think about string theories of *hadrons* during the 1974-84 period. In my opinion, it makes good sense to seek a hadronic string theory, even if one is convinced that QCD is correct. QCD describes the strong force in terms of fields that correspond to free quanta in the ultraviolet limit. At low energies (or long distances) these fields are strongly coupled and analytic calculations are impossible. A string description should be a good approximation in the infrared, the free string modes bearing close resemblance to the physical mesons. (Baryons would arise as skyrmions, as one knows from studies of sigma models.)

During the 1973-74 academic year, just at the time that string theory was falling out of favor, Joël Scherk spent half a year visiting Caltech. We both felt strongly that string theory was too beautiful a mathematical structure to be completely irrelevant to nature. After a while it occurred to us that many of its defects could be turned into virtues if it was used for a completely different purpose than that for which it was originally developed. One of the nagging problems that had bugged us for years was the inevitable occurrence of a massless spin-two state in the closed-string spectrum. We suggested interpreting this state as a physical graviton and regarding string theory as a candidate for a unified theory of all fundamental particles and forces rather than as a theory of hadrons.[10] Using a general argument of Weinberg based on gauge invariance,[11] we proved that low-energy graviton interactions in string theory agree precisely with general relativity. (This argument was also made independently by Yoneya.[12])

The reinterpretation of string theory as a unified theory containing gravity was a radical change in viewpoint. In order to achieve the correct value of Newton's constant, the fundamental length scale needed to be the Planck length, some
fundamental length scale needed to be the Planck length, some
20 orders of magnitude smaller than a hadron. Such length scales seemed absurd to particle physicists of the time, since they are way beyond anything that can be probed experimentally. (Grand unified theories, which involve distances only a few orders of magnitude larger, were introduced at about the same time.) As students, we had been taught that gravitational forces are completely negligible in particle physics. There was a sharply defined division in the sociology of the profession between the relativists who study gravitation (usually as a classical theory) and particle physicists who study the other forces. Therefore this was not only a difficult step for us, but it was a proposal for which there was no ready audience.*

In addition to accounting for the graviton, string theory had several other advantages that provided encouragement to Scherk and me. We knew that string theory had much softer ultraviolet behavior than point-particle field theories. Therefore we were optimistic that the nonrenormalizable divergences that plague all attempts to build a point-particle field theory including gravity could be avoided. Also, in gravity theories the geometry of space-time is dynamical, and so it seemed plausible to us that the extra dimensions could be wrapped up into an invisible ball. In this way the four-dimensional appearance of space-time could be accounted for.†

The inevitable appearance of gravitons and the good ultraviolet behavior of string theory convinced me that this was almost certainly the correct route to unification. Nonetheless, for ten years my best efforts to sell these ideas to others were rather unsuccessful. Some eminent physicists — such as Murray Gell-Mann and Edward Witten — took them seriously. Almost everyone else did not.

Space-Time Supersymmetry in String Theory

Supersymmetry was also discovered independently of the work on world-sheet supersymmetry that I have described. Gol'fand and Likhtman submitted a paper in March 1971 in which they formulated the *N=1* super-Poincaré algebra in four dimensions.[13] Wess and Zumino[14] wrote the seminal paper that made supersymmetry a cottage industry. It states very clearly that their motivation was to construct a four-dimensional analog of the two-dimensional symmetry that had been discovered in string theory.

Soon after the development of supergravity, Gliozzi, Scherk, and Olive (GSO) wrote an important paper examining the possibility of space-time supersymmetry in string theory.[15] They observed that since the spectrum of closed superstrings contains a massless gravitino in addition to the graviton, consistency of the theory requires that the entire spectrum form supersymmetry multiplets. As formulated by Neveu and me, this was not quite the case. However, GSO showed that a simple projection could be introduced to eliminate approximately half the states in the spectrum. Once this was done, they were able to demonstrate that the remaining ten-dimensional open string spectrum contains an
remaining ten-dimensional open string spectrum contains an
equal number of physical bosons and fermions at each mass level. This was compelling circumstantial evidence for space-time supersymmetry of the string theory, although a proof was still lacking.

In July 1979 (while visiting CERN) I began an intense and intellectually exhilarating collaboration with Michael Green. In the six subsequent years we spent a large part of our time working together — mostly at Caltech, but also at the Aspen Center for Physics and Queen Mary College in London. On several occasions, Lars Brink also participated in the work. Our first several papers dealt with reformulating superstring theory in a form that makes space-time supersymmetry

* The development of supergravity and Kaluza-Klein theory during the subsequent decade produced a generation of young theorists accustomed to thinking about gravitation in a particle physics context. Most of these people now work on string theory.

† The misleading term 'spontaneous compactification' was introduced to describe this possibility. I used to express my misgivings by saying it was 'spontaneous, but not unrehearsed.'

manifest.[16] In retrospect, it seems strange that it took so long to examine the question of space-time supersymmetry in string theory. When Mike Green and I returned to the question, it took about a year of hard work to prove that this symmetry is indeed present, both in the particle spectrum and in the interacting theory. In those days one could work on these matters in a leisurely way in complete confidence that no one else was doing the same thing — quite a contrast to the present situation!

Following the demonstration of space-time supersymmetry for open (Type I) superstrings, we discovered the Type II closed string theories with extended space-time supersymmetry.[17] We gave a simple proof at one loop of the vanishing of amplitudes with three or fewer massless external lines (for both Type I and Type II superstrings), and conjectured that this would be true in all higher orders as well ('nonrenormalization theorem'). We evaluated four-particle amplitudes, demonstrating their finiteness at one loop. It was argued that this too should be true to all orders. Several papers describing superstring field theory in the light-cone gauge were also written.[18]

In an attempt to obtain a deeper understanding of space-time supersymmetry in string theory, we formulated a covariant world-sheet action with manifest space-time supersymmetry.[19] Specifically, we found that the action

$$S = -\frac{1}{2\pi}\int d^2\sigma\sqrt{h}\,h^{\alpha\beta}\Pi_\alpha\cdot\Pi^\beta \tag{11}$$

$$-\frac{i}{\pi}\int d^2\sigma\,\varepsilon^{\alpha\beta}[\partial_\alpha X^\mu(\bar\theta^1\Gamma_\mu\partial_\beta\theta^1 - \bar\theta^2\Gamma_\mu\partial_\beta\theta^2) +$$

$$+ i\bar\theta^1\Gamma^\mu\partial_\alpha\theta^1\bar\theta^2\Gamma_\mu\partial_\beta\theta^2]$$

has $N=2$ global supersymmetry in ten dimensions:

$$\delta\theta^A = \varepsilon^A \tag{12}$$
$$\delta X^\mu = i\bar\varepsilon^A\Gamma^\mu\theta^A.$$

In these equations, ε^A *and* θ^A $(A = 1, 2)$ are Majorana-Weyl spinors, Γ_μ are ten-dimensional Dirac matrices, and

$$\Pi^\mu_\alpha = \partial_\alpha X^\mu - i\bar\theta^A\Gamma^\mu\partial_\alpha\theta^A. \tag{13}$$

This action is supposed to describe the same string physics as

This action is supposed to describe the same string physics as the NSR formulation (with GSO projection) even though it has no world-sheet fermions or world-sheet supersymmetry.

The equivalence of this action to the NSR one is well understood (by bosonization) in the light-cone gauge.[20] However, covariant quantization of the action given above has proved to be very challenging, because it contains a complicated mixture of first-class and second-class constraints. There is a large recent literature devoted to this problem, but it remains to be demonstrated that any proposal gives a practical scheme for evaluating amplitudes and analyzing the theory.

The 1984 Superstring Revolution

One issue that surfaced as crucial during the early 1980s was the need to understand chiral structure (left-right asymmetry) of the standard model. All the popular supergravity theories were nonchiral, and it was pretty clear that a chiral structure could not arise spontaneously. Two of the three known ten-dimensional superstring theories were chiral (type I and IIB). This was good, because it meant there was a chance of accounting for chiral four-dimensional physics. It was also dangerous because it meant the theories were threatened by gauge anomalies that would make them inconsistent.

The type I superstring theory can be formulated for any classical gauge group. The low-energy limit gives ten-dimensional supersymmetric Yang-Mills theory (coupled to supergravity). It was shown that hexagon diagrams (analogous to triangle diagrams in four dimensions) give a gauge anomaly for the Yang-Mills theory for every possible choice of gauge group. Most experts seemed to believe that string corrections could not improve matters.

The anomaly problem haunted us throughout the 1980-84 period. On several occasions I tried with Mike Green, with my student Neil Marcus, or by myself to evaluate the relevant hexagon diagram. However, the calculations always got bogged down and no clear conclusions could be drawn. Some remarks can be found in my 1982 Physics Reports article.[21]

The fundamental paper of Alvarez-Gaumé and Witten, entitled 'Gravitational Anomalies,' gave formulas for the contribution to gauge, gravitational, and mixed anomalies of chiral fermions and self-dual tensor gauge fields in any dimension.[22] The most striking example they analyzed was type IIB supergravity in ten dimensions.[23] *A priori*, it could have three distinct types of gravitational anomalies characterized by the 12-forms $tr\,R^6$, $tr\,R^2\,trR^4$, and $(tr\,R^2)^3$. They discovered that the coefficients of each of the three terms vanished as a consequence of remarkable cancellations among the various contributions. This made it very plausible that the type IIB superstring would also be anomaly-free. (I had expected this to be the case, since Green and I had found that the one-loop string amplitudes are finite.)

In the summer of 1984, I organized a workshop on 'physics in higher dimensions' at the Aspen Center for Physics. Many leading experts on anomalies, such as Bardeen and Zumino, were there. This proved to be very fortuitous. Green and I discussed the anomaly problem with Friedan and Shenker. They suggested trying to do the calculation in the old NSR formalism rather than the newer one that we had just

formalism rather than the newer one that we had just

developed. This proved to be a good idea, because the space-time supersymmetric formalism could only be used in light-cone gauge, which is very awkward for analyzing anomalies. Physically, anomalies correspond to the coupling at one loop of longitudinally polarized gauge particles, which ought to be decoupled as a consequence of gauge invariance. This leads to a breakdown of unitarity at two loops and beyond. In a physical gauge (such as light-cone gauge) unphysical modes are banished by the formalism from the outset. Therefore the inconsistency must show up elsewhere — namely in a breakdown of Lorentz invariance. Unfortunately, this is extremely difficult to recognize in a formalism that isn't manifestly Lorentz invariant in the first place. In the NSR formalism the calculation could be done covariantly.

After a period of struggle and confusion, Green and I found a good way of introducing a regulator and succeeded in getting a nonzero result for the planar diagram contribution to the hexagon gauge anomaly. At first this didn't make us too happy, because it confirmed what everyone had said — type I superstrings have gauge anomalies. We also calculated the Möbius strip diagram, which gave an anomaly of the same form.

The next day, just before one of the workshop seminars, I remarked to Mike that maybe there is a group for which the planar and Möbius strip anomalies cancel. At the end of the seminar, Mike said to me *'SO(32).'* Then we started getting excited. But we were not yet convinced that this was important because there were potentially several distinct gravitational and mixed anomalies, and we had no evidence yet for their cancellation.

After a while we decided to try to understand our result in terms of a low-energy effective field theory — namely supergravity coupled to super Yang-Mills theory in ten dimensions. I remembered that George Chapline and Nick Manton had been working on precisely that problem the previous summer in Aspen,[24] so we studied their paper carefully. Drawing on it, the formulas of Alvarez-Gaumé and Witten, and the wisdom of Bardeen and others, the picture became clear pretty quickly. We showed that for *SO(32)* all gauge, gravitational, and mixed anomalies could cancel at low energy.[25] This depended crucially on string corrections (such as the Lorentz Chern-Simons term) to the low-energy field theory. Now we were excited! But still, given our previous experiences, neither of us had any idea of how sudden and enthusiastic the response of the physics world would be.

The next bombshell was the heterotic string of Gross, Harvey, Martinec, and Rohm (often referred to as the Princeton string quartet) in November 1984.[26] Mike Green, Peter West, and I had been hard at work on many of the essential ideas such as compactification of 16 dimensions on an even self-dual lattice. Our big mistake was not to consider treating left-movers and right-movers differently. The irony in this is that Mike and I had invented the type IIA superstring, which was the only previous model with distinct left- and right-movers. I think that others (including Ed Witten and Peter Freund[27]) were also close to discovering the heterotic string.

Soon thereafter came the wonderful paper of Candelas, Horowitz, Strominger, and Witten.[28] By studying field
Soon thereafter came the wonderful paper of Candelas,
Horowitz, Strominger, and Witten.[28] By studying field
theory limits, it showed how one could obtain remarkably realistic four-dimensional models by compactification of the $E_8 \times E_8$ heterotic string. It introduced physicists to manifolds they had never heard of (Calabi-Yau spaces) and introduced many essential ideas — embedding the spin connection in the gauge group, modding out by discrete groups, symmetry breaking by Wilson lines (following Hosotani), etc. Calabi-Yau compactification of heterotic strings still looks like a good bet for getting realistic physics. Following these developments, superstring theory became accepted as mainstream physics. Indeed some of the new converts seemed to believe that the end of physics was close at hand, which seemed to me a little naive.

Concluding Remarks

Since the exciting developments of late 1984 that I have just described, the study of superstrings has become a very active and fertile area of research. Many surprising connections with various branches of mathematics have turned up. It is very satisfying to witness the growth of interaction between mathematicians and physicists after a long period of separation. I think it is fair to say that the study of string theory holds great promise for the unification of particles and forces, but it has already done a great deal to unify disciplines.

References

1. P. Ramond, Phys. Rev. **D3** (1971) 2415.
2. A. Neveu and J.H. Schwarz, Nucl. Phys. **B31** (1971) 86.
3. A. Neveu, J.H. Schwarz, and C.B. Thorn, Phys. Lett. **35B** (1971) 529.
4. A. Neveu and J.H. Schwarz, Phys. Rev. **D4** (1971) 1109.
5. C.B. Thorn, Phys. Rev. **D4** (1971) 1112.
6. J.L. Gervais and B. Sakita, Nucl. Phys. **B34** (1971) 632.
7. D.Z. Freedman, P. Van Nieuwenhuizen, and S. Ferrara, Phys. Rev. **D13** (1976) 3214; S. Deser and B. Zumino, Phys. Lett. **62B** (1976) 335.
8. L. Brink, P. Di Vecchia, and P. Howe, Phys. Lett. **65B** (1976) 471; S. Deser and B. Zumino, Phys. Lett. **65B** (1976) 369.
9. A.M. Polyakov, Phys. Lett. **103B** (1981) 207, 211.
10. J. Scherk and J.H. Schwarz, Nucl. Phys. **B81** (1974) 118.
11. S. Weinberg, Phys. Rev. **135** (1964) B1049; Phys. Rev.**138** (1965) B988.
12. T. Yoneya, Prog. Theor. Phys. **51** (1974) 1907.
13. Yu.A. Gol'fand and E.P. Likhtman, JETP Lett. **13** (1971) 323.
14. J. Wess and B. Zumino, Nucl. Phys. **B70** (1974) 39.
15. F. Gliozzi, J. Scherk, and D. Olive, Phys. Lett. **65B** (1976) 282; Nucl. Phys. **B122** (1977) 253.
16. M.B. Green and J.H. Schwarz, Nucl. Phys. **B181** (1981) 502.
17. M.B. Green and J.H. Schwarz, Phys. Lett. **109B** (1982) 444.
18. M.B. Green and J.H. Schwarz, Nucl. Phys. **B218** (1983) 43; **B243** (1984) 475; M.B. Green, J.H. Schwarz and L.
18. M.B. Green and J.H. Schwarz, Nucl. Phys. B218 (1983)
43; B243 (1984) 475; M.B. Green, J.H. Schwarz and L.
Brink, Nucl. Phys. **B219** (1983) 437.
19. M.B. Green and J.H. Schwarz, Phys. Lett. **136B** (1984) 367; Nucl. Phys. **B243** (1984) 285.
20. E. Witten, p. 395 in "Fourth Workshop on Grand Unification," ed. P. Langacker *et al.* (Birkhauser, 1983).
21. J.H. Schwarz, Phys. Reports **89** (1982) 223.
22. L. Alvarez-Gaumé and E. Witten, Nucl. Phys. **B234** (1983) 269.
23. M.B. Green and J.H. Schwarz, Phys. Lett. **122B** (1982) 143; J.H. Schwarz and P.C. West, Phys. Lett. **126B** (1983) 301; J.H. Schwarz, Nucl. Phys. **B226** (1983) 269; P. Howe and P.C. West, Nucl. Phys. **B238** (1984) 181.
24. G.F. Chapline and N.S. Manton, Phys. Lett. **120B** (1983) 105; see also: A.H. Chamseddine, Nucl. Phys. **B185** (1981) 403; E. Bergshoeff *et al.*, Nucl. Phys. **B195** (1982) 97.

25. M.B. Green and J.H. Schwarz, Phys. Lett. **149B** (1984) 117.
26. D. Gross, J. Harvey, E. Martinec, and R. Rohm, Phys. Rev. Lett. **54** (1985) 502.
27. P.G.O. Freund, Phys. Lett. **151B** (1985) 387.
28. P. Candelas, G. Horowitz, A. Strominger, and E. Witten, Nucl. Phys. **B258** (1985) 46.

Interview with A.N. Matveev

Prof. A.N. Matveev, former Unesco Assistant Director General for Science and Member of the ICTP Scientific Council, was invited by Abdus Salam to spend two weeks at the Centre after twenty years from his last visit. He was interviewed by News from ICTP.

Prof. A.N. Matveev talking to Abdus Salam.

Q. *Professor Matveev, you were a Member of the Scientific Council of the Centre from 1965 to 1969. The Centre was very small then. When you were sitting in the meetings of the Council as a high-official of Unesco, did you foresee or expect such a development? What are, according to you, the reasons for this success?*

A. My membership to the Scientific Council of the Centre resulted from Abdus Salam's intention to involve Unesco as an equal partner with IAEA in the running of the Centre and from my desire as Assistant Director-General for Science of Unesco to develop in the most effective way Unesco's Science Programme. As a physicist, I knew Salam very well. He was a world-wide known physicist. But I also knew his organizational ability in pushing the idea of the Centre through IAEA. Therefore it would have been a serious mistake of it would have been a serious mistake of an Assistant Director-General for Science of Unesco not to involve into Unesco Science Programme such a prospective figure as Abdus Salam. For me as a physicist such a mistake would have been like a treachery to the cause of international cooperation in physics. Therefore, from the very beginning, Abdus and I had full mutual understanding and unity of action. We knew very realistically the possibilities of all other parties involved and did not overestimate them. I can say that I did foresee and expect such a development which had really taken place during the first stage of the Centre's operation.

But I could not foresee a date when Salam would become Nobel Prize winner and I could not foresee the Centre development after this event. The Centre's development after this event surpasses all even most imaginative expectations. I can only admire all what has been done in developing the Centre and what has been and is being done by the Centre for international scientific cooperation in physics.

The answer to the last part of your question "What are the reasons for this question "What are the reasons for this success?", is absolutely clear to me: Salam as the driving force of the Centre's development and the good will of the Italian Government and Trieste community.

Q. *When you returned to the Soviet Union after your term with Unesco, did you remain active in international scientific co-operation through Unesco?*

A. After returning to the Soviet Union, I remained active in international scientific cooperation through Unesco. I was a member of the governing board of the Unesco Institute of Educational Planning for two terms. Also for two terms I served as a Member of the International Commission for Physics Education of the International Union of Pure and Applied Physics which acts in close cooperation with Unesco. At Unesco's requests, I took part in various missions, studies etc.

Q. *Soviet physics and mathematics are first class. The Centre has always had the co-operation of Soviet scientists even when the East-West relations were even when the East-West relations were not as good as they are nowadays. Now that the horizon looks wider, how do you see the collaboration between Soviet scientists with the developing countries and with the West?*

A. Without any doubt, the collaboration between Soviet scientists with the developing countries and with the West will be an important factor of future international scientific co-operation, but modalities of collaboration may change in accordance with developments in the Soviet Union.

A.M. Hamende

— • —

Prof. Alexej Nicolayevich Matveev was born in 1922 in Moscow. In 1940, he graduated from secondary school in Moscow, joined a military Air Force school and became a pilot. He took active part in World War II as a pilot of the Soviet diving bomber Pe-2 (Petljakov-2) after piloting for some time the American planes Boston A-20B and Boeing B-25. He made about 150 combat military raids. He was shot down several times, was wounded, and parachuted from his plane. He was awarded five highest military decorations.

In 1947, at the age of 25, he studied at the Physics Department of the Moscow State University where he continued to work after graduation in 1952. In 1954, he became Ph.D. and in 1959 Doctor of Science. In 1960 he was elected as full professor of Moscow State University. From 1964 untill 1969 he was Assistant Director-General for Science at Unesco after having spent two years in Egypt as a Unesco expert.

A.N. Matveev has published about 150 scientific papers and is author of 15 books, including a five-volume textbook of general physics, accepted in the USSR as a basic source for teaching physics at the university level. He has been honoured with the State Prize, the Lomonosov Prize and has other scientific distinctions. Many of his books were translated into English, Spanish and other languages, the first translation being his book "Principles of Electromagnetism", published by Reinhold's Publishing House in USA in 1965.

Quantum Field Theory and Politics: Prof. Oliviu Gherman

Professor O. Gherman, Vice-President of the Romanian Senate, was at the ICTP from 16 August to 6 September. Prof. Gherman has visited the Centre many times in the past as a field theorist. He was interviewed by News from ICTP.

Q. *Professor Gherman, you teach quantum field theory in Craiova and at the same time you are Vice-President of the Senate of Romania. This is a rather exceptional situation. Could you tell us how this happened?*

A. With respect to the first part of your question, I hope that my teaching quantum field theory at the University of Craiova is a natural consequence of my interest (and partially of the published papers) on the subject. My presence as senator is an exceptional situation only for people who did not live in communist countries and especially in Romania. During the dictatorial regime of Ceausescu a significant vacuum of politicians has developed. In those times, to be involved in politics would mean either to try to become one of his unconditional servants or to be excluded from the society if you opposed his politics (and eventually being sent in a special hospital with a diagnostics of mental disease!). The people around the dictator were a people of yes-men. In the last years I refused any responsibility (head of department, member of the university's senate etc.) but I did not have the courage to become an open dissident (with all the non negligible results). In this respect I consider myself as being guilty.

Immediately after the Revolution, the country was faced with tremendous problems in practically all areas. The people with some social prestige and some ideas about democracy were divided into two main groups. Some started to do their best to participate in the efforts of putting the country on the right tracks. Others preferred to criticize everything, to show their discontent with the decisions made. As I am deeply involved in all the aspects of the
involved in all the aspects of the
university life, I tried to do my best to direct correctly the activity in our university. Many of my colleagues from Craiova, Bucharest, Cluj or Timişoara as well as my former students persuaded me to run for the Romanian Parliament. I was conscious that such a step would mean a host of new responsibilities, but I considered that in the period of putting the basis of democracy in our country after a half of century of dictatorship any reserve on my part would mean deserting a patriotic duty. So, I ran, was elected and — to my surprise — elected as Vice-President of the Senate of Romania. Obviously my responsibilities towards the people who elected me increased correspondingly.

As I accepted these political responsibilities only for one mandate (this most difficult one, when we must pave the way to democracy) I asked, and the Senate was so generous to allow me to maintain my academic activities in the University.

As a conclusion, I consider that at least 70 percent of my colleagues from the Chamber and from the Senate are newcomers in politics in a situation similar to mine. I hope that we can contribute to the elaboration of good, democratic fundamental laws, including the constitution.

Professor Oliviu Gherman, Vice-President of the Romanian Senate, and theoretical physics.

Q. *Scientists in the "hard" disciplines" often complain that their role is not sufficiently understood by politicians*
often complain that their role is not
sufficiently understood by politicians (this may not be true in Romania). Do you share this opinion and if so, do you think that your work at the Romanian Senate could improve this situation?

A. This problem has been analysed many times brilliantly by the Director of the Centre — Professor Abdus Salam. I fully agree with his point of view which is the philosophy of the existence and usefulness of the Centre. Very often, Professor Salam explained that the role of the fundamental research is essential in the development of the countries. As far as I know, the main scope of the Centre is to help the development of the fundamental research in those countries which are economically less developed. As Professor Salam explained, this is not a utopia; on the contrary, this is a vital necessity. The opinion of those politicians who encourage the scientific researches only if these have a direct measurable effect could be compared with the point of view of blind people whose universe ends at the end of their sticks. In Romania, during Ceausescu's regime, all the scientists working in research institutes had to cover their salary by solving practical (or so-called practical) problems under contracts with industrial production units. Even the staff of the Universities had to cover 3/10 of their salary with such contracts. The beginning of every year meant a calvary to run for obtaining such contracts.

Even if occasionally I obtained important results in solving these contracts I consider that the scientific life is today so dense, the tension of a serious scientific activity is so strong, that any disturbance, even a minor one, could be disastrous for the whole activity. Therefore, I would try to become in our Senate the spokesman of the opinions so clearly and powerfully expressed by Professor Salam advocating for understanding that the main spur to a rapid development of a country is the encouragement of fundamental research with all possible means and with a national financial effort not last. For me, it is obvious that the greatest practical power has the theory deeply understood.

Q. *Romanian physicists and mathematicians who have come to work at the Centre were always excellent. Can you give your opinion on the quality of the scientific manpower in your country and on the problems which your scientists have to face now.*

A. It is not a secret that year by year our young fellows of the Romanian colleges won excellent places (recently the first ones) in the international competitions in mathematics, physics, chemistry, biology. So we have and we had excellent human resources among our students. Their ambition was always to overtake the results of their professors, despite the fact that during the last fifteen, and even more years, practically no one of those who graduated brilliantly, was promoted in research or in a university career. I consider this as a miracle and I do not know if I would have their strength for disregarding the irresponsible attitude of our government and to work so hard without any social perspective. This explains their high scientific level. This explains also the fact that among the scientists who have come to work at the Centre there were only few young ones.

I think that potentially we have in Romania a sufficient scientific manpower but we have to develop programmes urgently to recover those promising people who graduated in the last fifteen years and who were spread in unfruitful activities (teachers, technicians in factories etc.) and to develop a national programme for the salvation of the scientific activity in general. We strongly need help in completing our scientific information, as in the last two decades we practically did not receive any journal or book (duplication machines are essentially in this respect). At the same time we must encourage research in fields masterly selected which are in the forefront of the present scientific activity but which do not require huge expenses. It is useless to say that our experimental techniques is in at least as a disastrous situation as the scientific information. So the good choice of the lines of our scientific activity in the experimental fields has a national and vital importance. I can say that our destiny depends on this choice! The Centre could help us by helping to participate in those international research programmes which considers that would be of the highest relief for our progress.

Q. *As you know, the co-operation between the Romanian scientific community and the Centre has always been good. How do you see this collaboration for the future?*

A. I think that your appreciation is rather generous. The past cooperation was principally due to the Centre's efforts and its financial generosity. Even if we need more support from the Centre in the future (participation of Romanian scientists to the activities of the Centre), I think that the cooperation should be understood on much wider basis. The cooperation should be extended out of the traditional fields (physics and mathematics) to other fields of equal importance, in which we have eminent scientists (chemistry, medicine, engineering, meteorology etc.). On the other side, I think that Romania, in return, could offer excellent conditions for organizing some of the Centre's activities (some workshops, season schools, seminars). I think that by organizing at our expenses, in Romanian currency, some of the Centre's activities (and we can do that in excellent conditions) our cooperation will permit us to work on two legs rather than one, the Centre being able to accept more Romanian scientists to its own programmes.

Professor Oliviu Gherman was born on 26th April 1930 in Mihai-Viteazu, Cluj, Romania. He studied at the Faculty of Mathematics and Physics, Cluj and Bucharest, from 1948 to 1952. He obtained his Ph.D. in mathematical-physical sciences in 1956. He worked as assistant, lecturer, reader at the Physics Department, University of Cluj, and from 1966 he has worked as Professor of theoretical physics at Craiova University. Between July 1958 and January 1960 he worked as Officer at IAEA in Vienna. From 1965 to 1966 he was Dean of the Faculty of Physics in Cluj and from 1966 to 1968 Prorector of the Craiova University. He has published works in classical electrodynamics, statistical physics and quantum field theory. He is married and has two children. He has visited the ICTP eleven times.

A.M. Hamende

C.V. Raman Prize

The annual ICTP Prize, this time dedicated to C.V. Raman, has been awarded to Professor José Luis Morán-López, a solid state physicist, from the Universidad Autónoma de San Luis Potosí, Mexico.

Professor Abdus Salam, Director of the International Centre for Theoretical Physics, chaired the award ceremony in

José Luis Morán-López receiving the diploma of the C.V. Raman Prize from A.N. Matveev. Abdus Salam is in the middle of the photograph.

the Main Lecture Hall of the Centre on 16 July 1990. Prof. A.N. Matveev, former Unesco Assistant Director General for Science, read the citation. The most important contribution of J.L. Morán-López refers to surface magnetism, a domain in which he is one of the world leading experts. In 1987, he discovered a surface first-order phase transition in ferromagnets. More recently, he investigated quasi-crystals and Fibonacci chains and high-T_c superconductivity with successful results.

Prof. José Luis Morán-López was born in Charcas (Mexico) on 25 August 1950. He obtained his B.Sc. and M.Sc. in San Luis Potosí in 1972 and 1974 respectively and his Ph.D. at the Free
respectively and his Ph.D. at the Free
University of Berlin in 1977. He was a post-doctoral fellow of the National Council of Science and Technology (Mexico) in 1977-79, a Guggenheim Fellow in 1984-85 and a Research Associate of the ICTP from 1985 onwards. He has been a Visiting Professor in Berlin (Free University) in 1979, Porto Alegre (Brazil) in 1982, in Jülich (Federal Republic of Germany) in 1985 and in Strasburg in 1984-85.

He is the author of 121 papers and editor of 3 books. He founded the Mexican Society of Surface and Interface Physics. He was the Vice-President of the Mexican Physical Society in 1987-88 and has won two important Mexican Awards.

The ICTP annual Prizes are awarded to scientists from developing countries who have made outstanding contributions to physics. They are dedicated each year to distinguished scientists. The 1989 Prize was in honour of Chandrasekhara Venkata Raman, the great Indian scientist who won the Nobel Prize in 1930 and who did so much for the advancement of science in India.

Annual ICTP Prizes were created in 1982 by the Scientific Council of the Centre in recognition of outstanding contributions to physics and mathematics by scientists from and working in a developing country. They consist in a medal, a certificate and a US$ 1,000 cheque. One Prize is awarded each year.

In the same ceremony, four local personalities — politicians Dario Rinaldi and Giovanni Di Benedetto, and Prof. Guido Gerin and Prof. Giampaolo de Ferra who had served in the past as representatives of the Italian Government to the International Atomic Energy Agency of which the Centre is a part — received ICTP medals from P. Budinich, Deputy Director of the ICTP from 1964 to 1978, in recognition of their activity in favour of the Centre.

A.M. Hamende

Fields Medal to Edward Witten

On 21 August, one of the four Fields Medals 1990 was awarded to Edward Witten (Institute for Advanced Study, School of Natural Sciences, Princeton, NJ, USA) a great friend of the ICTP, for his new ideas in theoretical physics, which he applied to

From left to right: Prof. Giampaolo de Ferra, Prof. J.L. Morán-López, Prof. Guido Gerin, Dr. Giovanni Di Benedetto, Professor Abdus Salam, Dr. Dario Rinaldi and Prof. P. Budinich.

mathematics (supersymmetry, string theory and loop spaces).

Prof. Witten has visited the ICTP on many occasions. He won an ICTP Dirac Medal in 1985.

Maxwell Prize to R.N. Sudan

At its November 1989 meeting in Anaheim, California, the APS division of plasma physics presented the James Clerk Maxwell Prize for Plasma Physics to Ravindra N. Sudan of Cornell University. Sudan received the prize for his "wide-ranging contributions to the theory of plasma stability and turbulence, and pioneering work on the generation and propagation of intense ion beams," which have had "considerable impact on ionospheric and magnetospheric physics, on confinement and heating in field-reversed ion rings, and on light-ion-beam drivers for inertial confinement fusion."

Sudan received his Ph.D. in electrical engineering from Imperial College of the University of London in 1955. He joined the Cornell faculty in 1959 and became director of the Laboratory of Plasma Studies and IBM Professor of Engineering in 1975.

R.N. Sudan was associated with the ICTP research group in plasma physics in 1965-66 and has come back many times as a lecturer since.

Appointments

Appointments

News from ICTP welcomes communications on appointments and news on ICTP scientists for publication.

L. Lederman President-Elect of AAAS

Leon Lederman, director emeritus of Fermilab and professor of physics at the University of Chicago, is the new president-elect of the American Association for the Advancement of Science.

He has been a Member of the ICTP Scientific Council since 1989.

Visits to ICTP

Prof. Paolo Fasella (Italy)

Prof. Paolo Fasella, a biochemist and Director General of the European Economic Community's General Directorate for Science, Research and Development, took part in the Dirac Medal Ceremony on 4 July. He had discussions with ICTP and TWAS officials on future possible avenues of collaboration with the EEC.

Austrian Minister for Research

Mr. Ehrard Busek, Austrian Minister for Research, and several of his collaborators, visited the Centre on 16 July 1990. They were received by Abdus Salam, Director of the ICTP and President of the Third World Academy of Sciences. After a conversation with the Director, the group which also included the Austrian Consul in Trieste, Dr. Birbaum, was briefed on the Centre's programmes and on prospects of cooperation by L. Bertocchi, Deputy Director of the ICTP. The collaboration with the Austrian scientists is excellent. The Centre welcomes about 30 of them every year. After the lunch, the Austrian Delegation visited other components of the "Trieste System": the UNIDO International Centre for Genetic Engineering and Biotechnology, and the site of the future synchrotron light laboratory.

Minister Kuhanga (Tanzania)

The former Vice-Chancellor of the University of Dar-es-Salaam and Minister of Education, Hon. Nicholas Kuhanga visited the ICTP on 30 July 1990. He is currently Chairman of the National Committee in charge of establishing an Open University in Tanzania.

Conferences and Lectures

- Prof. Mbaro-Saman Lubuma, Visiting Scientist at ICTP in the Mathematics Research Group, presented a paper on "A Mixed Finite Element Method for the Mixed Dirichlet-Neumann Problem for the Stokes Operator on a Polygon" at the Fourth International Congress on Computational and Applied Mathematics, Leuven, Belgium (23 - 28 July 1990).

- Prof. A. Shkrebtii, Visiting Scientist at ICTP in the Condensed Research Group, presented a paper on "The Atomic Structures of Reconstructed Si(110) Surface Phases", written in collaboration with C.M. Bertoni, R. Del Sole and B. Nesterenko, at the 20th International Conference on the Physics of Semiconductors, Thessaloniki, Greece (6 - 10 August 1990).

Abdus Salam receives Mr. Ehrard Busek, Austrian Minister for Research (at the centre of the photograph) and his collaborator.

Hot Papers

The articles listed below, all less than two years old, have received a substantially greater number of citations than others of the same type and vintage, according to data from *The Science Citation Index* of the Institute for Scientific Information, Philadelphia. Why have these research reports become such stand-outs? A comment following each reference, supplied to *The Scientist* by one of the authors, attempts to provide an answer.

PHYSICS

M. Büttiker, "Absence of backscattering in the quantum Hall effect in multiprobe conductors," *Physical Review B*, 38, 9375-89, 15 November 1988.

Markus Büttiker (IBM Thomas J. Watson Research Center, Yorktown Heights, N.Y.): "Eight years after the discovery of the quantum Hall effect, my paper presented a transport theory, which is particularly close to the setup actually used to measure the effect. Earlier theories that stressed the topological nature suggested that the quantum Hall effect is largely independent of the properties of the sample. In contrast, my discussion showed that the properties properties of the sample. In contrast, my discussion showed that the properties of the current source contact and current sink contact and the properties of the contacts used to measure voltages are of importance for the quantization of the resistance. Fortunately, since the publication of my paper, a number of groups from different parts of the world have carried out experiments that confirm my predictions. Most exciting, it was since discovered that the nonlocal effects that give rise to deviations from the quantum Hall effect persist over macroscopic distances."

SUPERCONDUCTIVITY

C.L. Kane, P.A. Lee, N. Read, "Motion of a single hole in a quantum antiferromagnet," *Physical Review B*, 39, 6880-97, 1 April 1989.

Charles Kane (IBM Thomas J. Watson Research Center, Yorktown Heights, N.Y.): "The interplay between doping and magnetism is a central issue in current theories of the high-temperature superconductors. The undoped compounds are generically antiferromagnetic insulators (such as La_2CuO_4), and many of the fascinating properties of these materials emerge when they are doped with holes. The holes are believed to be the charge carriers in these materials, and the presence of superconducting properties depends crucially on their concentration. In order to understand the normal and ultimately superconducting properties of these materials, it is therefore important to understand the nature of holes moving in an antiferromagnetic background.

"In this paper we formulate a quasiparticle theory of a single hole in a quantum antiferromagnet. We find that the mass of a hole is enhanced, since it tends to disturb the antiferromagnetic order as it moves. This quasiparticle theory for a single hole is a useful starting point for treating the more complicated and realistic problem of a finite density of holes, which would be the case in a doped antiferromagnetic material."

Articles Alert

From "The Scientist",
June 11 and June 25, 1990;

The Scientist has asked a group of experts to comment periodically upon recent articles that they have found noteworthy. Their selections, presented herein every issue, are neither endorsements of content nor the result of systematic searching. Rather, the list represents personal choices of articles the columnists believe the scientific community as a whole may also find interesting. Reprints of any articles cited here may be ordered through The Genuine Article, 3501 Market St., Philadelphia, Pa. 19104, or by telephoning (215) 386-4399.

MATERIALS SCIENCE

by Theodore Davidson, Institute of Materials Science, University of Connecticut, Storrs.

• Using polymers as precursors to ceramics offers some attractive possibilities. Polymers can be drawn into fibers or cast as films and then converted to ceramic materials. This has been accomplished already with carbon and SiC fibers and coatings. A recent synthesis of soluble polymers from the six-membered borazine ring has provided a precursor for boron nitride powder. Subsequent development could produce fibers or coatings.

P.J. Fazen, J.S. Beck, A.T. Lynch, E.E. Remsen, L.G. Sneddon, "Thermally induced borazine dehydropolymerization reactions. Synthesis of a new high-yield polymeric precursor to boron nitride," *Chemistry of Materials*, **2** (2), 96-7, 1990. (University of Pennsylvania, Philadelphia)

• In response to the concern over brittleness in oxide glasses, numerous strengthening approaches are examined. Surface modifications reduce the influence of surface defects, while bulk composition, phase separation, and fiber or particulate reinforcement may increase both strength and fracture toughness. Successes and limitations are evenly presented.

I.W. Donald, "Methods for
presented.

I.W. Donald, "Methods for improving the mechanical properties of oxide glasses," *Journal of Materials Science*, **24**, 4177-208, December 1989. (Atomic Weapons Establishment, Aldermaston, Berkshire, England)

• Controlling microstructure is a principal objective in much of materials science. Recently, several approaches have been taken to selectively place a second phase "guest" species in an ordered array of "host" molecules. With iron oxychloride (FeOCl) as the host lattice, intercalation can be achieved with species that transfer charge from guest to host. An interesting example involves aromatic hydrocarbons, such as perylene and tetracene. When these are intercalated into FeOCl, they raise the electrical conductivity of the host by a factor of 10^5. The resulting low-dimensional semiconductors have band gaps near 0.28 electron volts.

J.F. Bringley, B.A. Averill, "Aromatic iron intercalates: synthesis and characterization of iron oxychloride intercalated with perylene and tetracene," *Chemistry of Materials*, **2**, 180-6, March/April 1990. (University of Virginia, Charlottesville)

• In another host-guest situation, nanoparticles of cadmium sulfide can be sandwiched between the headgroups of an ordered organic array. Long-range order is created by dipping up a Langmuir-Blodgett (L-B) film of dioctadecyl-dimethylammonium chloride, adsorbing the CdS particles, and closing with a second L-B film. Measurements by low-energy electron diffraction, absorption spectroscopy, and scanning tunneling microscopy show that the cadmium sulfide retains its crystallinity and the multilayer forms a structured array.

S. Xu, X.K. Zhao, J.H. Fendler, "Ultrasmall semiconductor particles sandwiched between surfactant headgroups in Langmuir-Blodgett films," *Advanced Materials*, **2** (4), 183-5, 1990. (Syracuse University, N.Y.)

• The scanning tunneling microscope has opened new vistas from fundamental studies of single crystal surfaces to
studies of single crystal surfaces to
biological ultrastructure at the macromolecular level. It has also inspired a whole generation of new techniques in which the spatial resolution is better than the wavelength used for imaging. There are magnetic and electrostatic force microscopies; near-field optical, thermal, and acoustic microscopies—each with special capabilities. These are reviewed—with their limitations. And, included in the same issue are 136 other papers that were presented at the Fourth International Conference on Scanning Tunneling Microscopy/Spectroscopy.

H.K. Wickramasinghe, "Scanning probe microscopy: current status and future trends," *Journal of Vacuum Science and Technology*, **8A**, 363-8, January/February 1990. (IBM Watson Research Center, Yorktown Heights, N.Y.)

COMPUTATIONAL SCIENCE

by Bruce G. Buchanan, Department of Computer Science, University of Pittsburgh, Pittsburgh.

• Remote procedure calls (RPCs) allow a program running on one computer in a network to invoke a program on another machine. The design and implementation of parallel RPCs in the Andrew distributed computing environment at Carnegie Mellon University (CMU) are reported, and some of the advantages of this design are analyzed.

M. Satyanarayanan, E.H. Siegel, "Parallel communication in a large distributed environment," *IEEE Transactions on Computers*, **39**, 328-48, March 1990. (CMU, Pittsburgh)

• Error-free computation is impossible to guarantee, for reasons of failures in either hardware or software. A recent survey paper reviews the effects of software on reliability and describes a model of "resourceful systems." These systems can determine whether or not goals have been achieved, and, if not, will carry out alternative plans.

R.J. Abbott, "Resourceful systems for fault tolerance, reliability, and safety," *ACM Computing surveys*, **22**, 35-68, March 1990. (Aerospace
22, 35-68, March 1990. (Aerospace
Corp., Los Angeles)

• Circumscription is a technique for formalizing some aspects of common sense reasoning that introduces a requirement of minimality: If a formula, P, is satisfied, then no proper subset of P is. Finding ways to express circumscription without introducing second-order formulas has been an active research area. Results of this research are extended, and the computational complexity of model checking for circumscription is analyzed.

P.G. Kolaitis, C.H. Papadimitriou, "Some computational aspects of circumscription," *Journal of the Association for Computing Machinery*, **37**, 1-14, January 1990. (University of California, Santa Cruz and San Diego)

• Explanation-based learning is a relatively new technique for abstracting a solution to a specific problem. The solution will then be used on later problems, based on an explanation of why the solution works. Research is reported that extends the technique to generalize over iterative or recursive processes. Results of the BAGGER2 learning algorithm are presented.

J.W. Shavlik, "Acquiring recursive and iterative concepts with explanation-based learning," *Machine Learning*, **5**, 39-70, March 1990. (University of Wisconsin, Madison)

• Computer chess has become an area of intense interest. Better performance results in recent years are due to deeper searches that are allowed by faster and larger machines. An argument is made that increasing the amount of knowledge will also be necessary for World Championship programs. Several other articles about chess programs appear within the April issue of *Artificial Intelligence (AI)*.

H. Berliner, G. Goetsch, M.S. Campbell, C. Ebeling, "Measuring the performance potential of chess programs," *AI*, **43**, 7-20, April 1990. (CMU, Pittsburgh; University of Washington, Seattle)

Activities at ICTP

Activities at ICTP

in July-August 1990

Title: MINIWORKSHOP ON STRONGLY CORRELATED ELECTRON SYSTEMS, 18 June - 27 July 1990.

Organizers: Profs. G. Baskaran (Matscience Institute of Mathematical Science, Madras, India), A.E. Ruckenstein (University of California, San Diego, USA), E. Tosatti (International School for Advanced Studies, ISAS-SISSA, and ICTP, Trieste, Italy) and Yu Lu (Academia Sinica, Beijing, P.R. China, and ICTP), in collaboration with the International School for Advanced Studies (ISAS-

SISSA, Trieste, Italy).

Lectures: Perturbation theory and conserving approximations for correlated fermions. A brief review of NMR: applications. Introduction to low-dimensional magnetism. Optical properties of strongly correlated systems. Singlet quasi-particles in multi-band models of the high T_c oxides. Introduction to the 1/N approach to strongly correlated systems. Low temperature properties of 2-D orbital antiferromagnets and spin nematics. Approaches to the one dimensional Hubbard model. Cluster simulations of the Hubbard model. One particle excitations in strong coupling superconductors. Solution of the five-vertex model. Few electrons in the 2D Hubbard model. An introduction to the quantum Hall effect. Spiral phases in doped quantum antiferromagnets. The mean field (Hartree-Fock) anyon gas: a (insulating) sheep in wolf's clothing? Numerical approaches to strongly correlated systems. Comments on pseudo-gaps in correlated systems. Cumulant expansion study of holes in quantum antiferromagnets. A path-integral approach to the dynamics of holes and spins in the t-J model. Introduction to anyon superconductivity. Spiral mean field solution in the t-J model. A schematic model for high T_c superconductivity. Superconductors in very strong magnetic fields. Introduction to Luttinger liquids (in 1-D!). g-ology in 1 and 2 dimensions. Strong coupling techniques on the lattice. Dynamics of dilute holes in quantum antiferromagnets. Pairing with fractional dilute holes in quantum antiferromagnets. Pairing with fractional angular momentum and "spinor" gap. Field theory approach to the fractional quantum Hall effect. Gauge field theory of transport properties in strongly correlated systems. Introduction to large D expansions in strongly correlated systems.

The Miniworkshop was attended by 100 lecturers and participants (32 from developing countries).

Title: SUMMER SCHOOL IN HIGH ENERGY PHYSICS AND COSMOLOGY, 18 June - 28 July 1990.

Organizers: Prof. J.C. Pati (University of Maryland, College Park, USA), Dr. S. Randjbar-Daemi (ICTP), Dr. E. Sezgin (Texas A & M University, College Station, USA) and Prof. Q. Shafi (Bartol Research Institute, Newark, USA), in collaboration with the International School for Advanced Studies (SISSA, Trieste, Italy) and the Italian Institute for Nuclear Physics (INFN).

International Advisory Committee: Profs. G. Altarelli (CERN, Geneva, Switzerland), J. Ellis (CERN, Geneva, Switzerland), E. Fradkin (P.N. Lebedev Institute, Moscow, USSR), H. Nicolai (Universität Fridericiana Karlsruhe, Federal Republic of Germany) and Dr. J. Strathdee (ICTP).

Lectures: Introduction to conformal and superconformal theories. N = 2 superconformal theories. Landau Ginzburg orbifolds. String field theory. N = 2 solitons. Effective field theories in 4-dim. N = 2 strings. Quantum groups and its applications to conformal field theories. 2-dim. gravity. Quantum chromodynamics. Phenomenological supersymmetry. Beyond the standard model. Superstring phenomenology. An overview of recent developments in lattice gauge theories. Chiral perturbation theory and CP violation. Electroweak interactions and applications to e^+e^- physics. Standard big bang cosmology and primordial nuclear synthesis. Anomalous baryon and lepton number violation in the electroweak model. Quantum cosmology. Dark matter. Cosmic strings.

(Workshop on superstrings and matter. Cosmic strings.

(Workshop on superstrings and related topics): N = 2 strings and W symmetry. Background independence of string field theory. Topology change in string theory. W algebras and W gravity. The nucleation model of the Hagedorn phase transition. U(1) Chern-Simons and anyons on a torus. Cancellation of the Lorentz anomaly in light-cone gauge string field theory. 2-d gravity and related matters. The geometry of the super KP flows. Superstring in curved space: application of Krichever-Novikov formalism. New supersymmetries and higher spinors.

(Workshop on Phenomenology in high energy physics and cosmology): Current status of CP violation. Solar neutrinos. Survey of Calabi-Yau superstring phenomenology. Heavy flavour physics. Wormholes in the cosmological constant. Results from UA2. Results from LEP. Supersymmetry breaking and related topics. Physics at Gran Sasso. 4-dim superstring models. Results from CDF, Fermilab.

The School was attended by 273 lecturers and participants (171 from developing countries).

Title: ADRIATICO RESEARCH CONFERENCE ON QUANTUM FLUCTUATIONS IN MESOSCOPIC AND MACROSCOPIC SYSTEMS, 3 - 6 July 1990.

Organizers: Profs. H.A. Cerdeira (UNICAMP, Campinas, Brazil, and ICTP), F. Guinea (University of California, Santa Barbara, USA) and U. Weiss (Universität Stuttgart, Federal Republic of Germany), with the co-sponsorship of IBM-Italy and the International School for Advanced Studies (SISSA, Trieste, Italy).

Lectures: Change quantization effects in small tunnel junctions. Single electron effects in tunnel junctions. The quantum mechanical theory of transport in mesoscopic structures. Critical behaviour of dissipative quantum systems in the dense limit. Periodic orbit theory of dissipative tunneling. Change unbinding transition in junction arrays. Resistive superconducting ground state in a very small current biased Josephson junction. Path integral approach to the thermodynamics of Josephson junction. Path integral approach to the thermodynamics of quantum anharmonic phonons. Quantum diffusion of kinks in dislocations. Current experimental understanding of 1/f noise. The quantum mechanics of a macroscopic variable. Macroscopic quantum tunneling: how quickly must the environment react to affect it? Solitons and charging effects using STM. Conductance fluctuations and chaotic scattering. Charging effects in ultrasmall tunnel junctions. Relaxation theory of the spectral properties of dissipative two-state quantum systems. Universality in dissipative two-state systems. Vortex motion in inhomogeneous superconductors. Charge ordering and transport properties of

Josephson arrays and chains. Influence functional theory of a heavy particle in a Fermi gas. Effect of quantum fluctuations on DC electron transport in ultrasmall tunnel junctions. The effect of charge fluctuations on Coulomb blockade. Quantum dissipation on a disordered lattice: a simple tight-binding approach. Dimers, repulsion and the absence of localization. Classical effective XY-coupling constant for dissipative Josephson junction arrays. Aharonov-Bohm oscillations and non-local electronic conduction. Persistent currents and thermodynamics of mesoscopic systems. Coherence and persistent currents in mesoscopic rings. Transmission through dissipative barriers. Switching dynamics in Josephson junctions: thermal and quantum behaviour. Traversal time, dynamic polarization and photon emission in tunneling.

The Conference was attended by 54 lecturers and participants (8 from developing countries).

Title: ADRIATICO RESEARCH CONFERENCE PHYSICS OF STRONGLY CORRELATED SYSTEMS, 10-13 July 1990.

Organizers: Professors G. Baskaran (Institute for Mathematical Science, Madras, India), A.E. Ruckenstein (Rutgers University, Piscataway, USA), E. Tosatti (SISSA and ICTP, Trieste, Italy) and Yu Lu (Academia Sinica, Beijing, P.R. China, and ICTP), with the co-sponsorship of IBM-Italy and Consiglio Nazionale delle IBM-Italy and Consiglio Nazionale delle Ricerche (Italy).

Lectures: Overview of the experimental status of high T_C. Model studies of transport in strongly correlated systems. Gutzwiller approach to the Kondo-lattice problem. Frustration, phase separation and superconductivity. Finite cluster studies of strong correlation models. Quantum Monte-Carlo studies of the Hubbard model. Interacting fermions in low dimensions from weak to strong correlation. Eigenfunctions fro 2D square and strip Fermi surfaces. Correlation functions of 1-D Hubbard model: zero-field and finite-field cases (large U). Theory of Raman scattering in Mott-Hubbard systems. Finite size scaling and exponents of the 1-D Hubbard model. Landau's theory of the Luttinger liquid. Anyon superconductivity and fractional quantum Hall effect. Orbital ferromagnetism of anyons. Spin singlet vs. spin polarized states in FQHE. Exact statements about the Hubbard model. New large N limits for frustrated antiferromagnets and superconductivity in the t-J model. Structure of vortices in the classical Ginzburg Landau Chern-Simons theory of quantum Hall effect. Molecules with strongly correlated electrons. Exact mean field theory for fermionic lattice models. Raman scattering in high T_C superconductors. Phase separation in the t-J model. Pairing of spatially separated electrons and holes in high T_C materials.

The Conference was attended by 62 lecturers and participants (19 from developing countries).

Title: SYMPOSIUM ON FRONTIERS IN CONDENSED MATTER PHYSICS, 11-13 August 1990.

Organizers: Professors E. Burstein (University of Pennsylvania, Philadelphia, USA), P. Chaudhari (IBM, Yorktown Heights, USA), J.R. Schrieffer (University of California, Santa Barbara, USA), E. Tosatti (International School for Advanced Studies, ISAS-SISSA, and ICTP, Trieste, Italy), and Yu Lu (Academia Sinica, Beijing, P.R. China, and ICTP, Trieste, Italy).

Lectures: Properties of the blue electron. Is computing part of the future electron. Is computing part of the future of physics? Experimental approaches to superconductivity in oxides. The theory of high T_C superconductivity: the relation between weak and strong coupling approaches. Perspectives of local probe methods. Single electron tunneling in ultrasmall tunnel junctions. Ten years quantum Hall effect. Fractional quantum Hall effect. The fractional Hall effect and other uses of h/e2. The ecology computation. Superfluidity in neutron stars and its implication for the decay of their magnetic fields.

The Symposium was attended by 52 lecturers and participants (7 from developing countries).

Title: ADRIATICO RESEARCH CONFERENCE ON DEFECTS IN HEXAGONAL CLOSE PACKED CRYSTALS, 14-17 August 1990.

Organizers: Professors D.J. Bacon (University of Liverpool, UK), W. Frank (Max-Planck-Institut für Metallforschung, Stuttgart, Federal Republic of Germany), E.J. Savino (Comisión Nacional de Energía Atómica, Buenos Aires, Argentina), S. Seeger (Max-Planck-Institut für Metallforschung, Stuttgart, Federal Republic of Germany), M. Tosi (University of Trieste and ICTP, Italy), V. Vitek (University of Pennsylvania, Philadelphia, USA) and C.H. Woo (Atomic Energy of Canada Ltd., Pinawa, Canada), with the co-sponsorship of Atomic Energy of Canada Ltd. (Canada), CANDU Owners Group (Canada), Commission of the European Communities (Belgium), IBM-Italy and the International School for Advanced Studies (ISAS-SISSA, Trieste, Italy).

Lectures: Collapse of displacement cascades in hexagonal close-packed metals. Microstructure evolution in hexagonal close-packed metals during irradiation. Radiation damage and the properties of vacancies and self-interstitials in Cd and Zn. Defect-complexing and annealing in Cd and Zn. Electrical resistivity measurements in cobalt and dilute cobalt alloys following low-temperature particle irradiation. Magnetic relaxation measurements in irradiated cobalt. Many body effects on calculated defect properties of hexagonal calculated defect properties of hexagonal close-packed metals. Point defects in HCP metals—a review. The formation and migration energies of vacancies in boundaries in HCP crystals. Lattice defects in rare earth metals. Self-interstitials, vacancies and diffusion mechanisms in HCP metals. Rate theory analysis of radiation damage effects near surfaces in hexagonal metals. Point defects and sink strength in HCP materials. Defects in HCP crystals. Self-diffusion and fast impurity diffusion in the bulk and in grain boundaries of hexagonal titanium. Interphase and grain boundary diffusion in a-Zr and Zr-Nb alloys. Rutherford back scattering diffusion studies of Hf in a-Zr. The low-temperature plasticity of HCP metals and alloys: the case of titanium-Y alloys. Topological theory of discontinuities in crystals and interfaces: application to hexagonal crystals. Deformation twinning in hexagonal close-packed metals and alloys. Structure and properties of twinning dislocations in HCP metals. A study of the stress state leading to twinning activation in HCP metals. Grain boundary strengthening associated with S9 near coincidence boundary in <10T0> twist Zinc bicrystals. Observations of grain boundary structure in zinc. The low temperature plasticity of HCP metals and alloys: the case of titanium. Prismatic glide in divalent HCP metals. Dislocation core structure in hexagonal close-packed metals. Glide mechanism of 1/3 <TT23> {10T1} dislocations in Ti and Zr. Deformation of Ti_3Al single crystals. The relative stability of the alpha and omega phases in some Zr based alloys. Internal friction studies of hydrogen and hydride precipitation in a-Zr and a-Ti — a review.

The Conference was attended by 62 lecturers and participants (22 from developing countries).

Symposium on Frontiers in Condensed Matter Physics, 11-13 August 1990.

International Centre for Theoretical Physics
of IAEA and UNESCO
Strada Costiera, 11
P.O. Box 586
34136 Trieste
Italy

Telephone: (40) 22401
Cable: CENTRATOM
Telex: 460392 ICTP I
Telefax: (40) 224163
Bitnet: POSTOFFICE@ITSICTP.BITNET
Decnet: VXICP1::POSTOFF
Itapac: 022224110125