



# Patilka

January 1988 No.16 Newsletter of the Indian Academy of Sciences

## 53rd Annual Meeting

At the invitation of the Regional Research Laboratory, Hyderabad, the Academy held its 53rd Annual Meeting at RRL from Saturday 7 November to Monday 9 November 1987.

The meeting began with the inaugural function in the RRL Auditorium at 0930 hours on Saturday 7 November. Dr A V Rama Rao, Director, RRL, welcomed the delegates on behalf of the Local Organizing Committee. He traced the history of the RRL, which was established by the Government of Hyderabad in 1944 and which later in 1952, became a part of the CSIR national chain of laboratories, under the Department of Scientific and Industrial Research, with accent on research in chemistry and chemical technology.

Prof. O Siddiqi, President, introduced the Fellows and Associates present. He then gave his Presidential address on the organization of higher nervous systems and the nature of visual and other types of perception.

This was followed by a Business Meeting of the Fellows.

There were two short specialized symposia and fourteen lecture presentations by new Fellows and Associates during the Meeting.

The first series of lectures by Fellows and Associates, under the chairmanship of Prof. O Siddiqi, was held in the afternoon of 7 November in the auditorium of the National Institute of Nutrition. The first talk was by D Mukherjee of the Indian Association for the Cultivation of Science, Calcutta "On the use of size-extensive and size-consistent models in quantum chemistry".

This was followed by a talk on "Defects in liquid crystals" by G S Ranganath of the Raman Research Institute, Bangalore. Under a polarising microscope liquid crystals exhibit beautiful

characteristic optical patterns called textures, due to an assembly of topological defects. Such defect states are also found in superfluids, magnetic spin systems, crystals etc. but in liquid crystal systems topological defects can be studied with a simple optical technique.

The evening lecture that day was given by K G Ramanathan of the Tata Institute of Fundamental Research on "The life and work of Srinivasa Ramanujan". A summary of this lecture is given in this issue.

The first symposium on **High temperature superconductivity** was held in the RRL auditorium in the forenoon of Sunday 8 November, under the chairmanship of Prof. T V Ramakrishnan. Five scientists, actively engaged in research in this important area, took part in the symposium. After a brief introduction by Prof. T V Ramakrishnan, E V Sampathkumaran of the Tata Institute of Fundamental Research gave the first talk on an "Overview of high temperature superconductors — experimental status". High temperature superconducting oxides can be broadly classified into two families. He showed that the temperature of these compounds at which they become superconducting is a very sensitive function of the oxygen content, and the position of the oxygen vacancy, in the second family of compounds.

A V Narlikar of the National Physical Laboratory, New Delhi next spoke on "High temperature superconductivity studies at NPL". Studies on high temperature  $T_c$  superconductors at NPL are on the substitution effects on  $T_c$ , the mechanism of superconductivity through various characterization techniques like Hall effect studies, Mossbauer spectroscopy, EPR etc, both quasi-particle and Josephson tunnelling and the nature of flux pinning and factors influencing the critical current density.

G Baskaran of the Institute of Mathematical Sciences, Madras spoke next on "The resonating valence bond state and high temperature superconductivity".

P Ganguly of the Indian Institute of Science, Bangalore spoke on the "Physico-chemical properties of copper oxides and high temperature superconductivity". He reported on his studies of magnetic susceptibility, EPR and optical spectra in the visible and infra-red regions, of some ternary copper oxides.

The last talk in the symposium was by G V Subba Rao of the Indian Institute of Technology, Madras on "High temperature superconductivity in rare earth-barium-copper-oxygen system of compounds". The high  $T_c$  ceramic oxide superconductor is amenable to chemical substitution and hence fine tuning of some of the superconducting properties, including  $T_c$ , is possible. He reported the synthesis of a large number of well-defined single phase materials.

There were five lecture presentations in the afternoon of 8 November, under the chairmanship of Prof. S Dhawan. N Viswanadham of the Indian Institute of Science, Bangalore spoke first on "Modelling and control of automated manufacturing systems".

He was followed by J Chandrasekhar, also of the Indian Institute of Science, Bangalore, on "Novel electronic effects in radicals and radical ions". He spoke of the use of ab initio and semi-empirical molecular orbital methods to make several predictions concerning unusual structural and electronic features associated with radicals and radical ions. A few representative examples were described.

The next speaker was A K Susheela of the All India Institute of Medical Sciences, New Delhi. She spoke on the "Emerging concepts in fluorosis research". Dental and skeletal fluorosis is a serious health problem in most states in the country, the main cause being ingestion/inhalation of fluoride in excess, through water, food, toothpaste, drugs and air. In dental fluorosis, the teeth become discoloured, with pitting and perforation, while in skeletal fluorosis, the clinical manifestations begin with pain in the neck, backbone and hip region and culminate in stiff, immobile and painful joints. Paralysis is a common occurrence in the late stages. Valuable information in understanding the pathogenesis of the disease and the nature of its affliction has now been collected as a result of the studies conducted at the AIIMS.

Ravi Mehrotra of the National Physical Laboratory, New Delhi spoke next on "Experiments on a single layer of electrons". He described a novel system, consisting of a single layer of electrons floating above a liquid helium surface between two horizontal metal plates forming a parallel plate capacitor. A positive voltage applied to the plate inside liquid helium at

temperatures below 1K controls the areal density of electrons, which float about  $70 \text{ \AA}$  above the helium surface. Such an electron system is an almost ideal 2D system, and has a very smooth substrate with no impurities. The electrons crystallize into a triangular solid below a certain temperature, the only Wigner solid known experimentally. One important advantage of this system is that the probe with which the electron layer is studied experimentally exists within the system, viz, by the ripples (quantized capillary gravity waves) on the liquid helium surface. If the motion of electrons is restricted in one of the two dimensions, it should be possible to reduce the dimensionality of this system from two to one.

The last talk was by A K Raychaudhuri of the Indian Institute of Science, Bangalore on "New dynamical experiments with spin-glasses". He presented measurements of dynamic susceptibility and dynamic elastic properties in the audio-frequency range made on a spin glass. They establish the importance of dynamic elastic measurements on spin-glasses as a new tool in the study of the dynamics of spin-freezing.

The evening lecture on 8 November was by Madhav Gadgil on "Bird life of India: In homage to Dr Salim Ali".

The second symposium on **Frontiers in Chemical Sciences** was held in the forenoon of Monday 9 November. There were five speakers. After a brief introduction by the chairman of the session Dr A V Rama Rao, G Mehta of the University of Hyderabad, spoke on "New strategies in organic synthesis". He was followed by P Balaram of the Indian Institute of Science, Bangalore, who spoke on "Approaches to the chemical synthesis of an artificial protein".

The next speaker was K N Ganesh of the National Chemical Laboratory, Pune, who spoke on "Synthesis, spectroscopic and structural studies of short DNA fragments". Protein-nucleic acid interaction is the single most important recognition system, crucial to most biological processes. In his talk he discussed new strategies for large scale synthesis of short DNA fragments.

B Venkataraman of the Tata Institute of Fundamental Research spoke on "Study of fast chemical reactions". The time scale of chemical reactions is known to spread over many orders of magnitude. A new scale, the pT scale, has been defined. With the advent of lasers, fast detectors and computers, it has become possible to probe directly into events which take place in time scales of the order of  $10^{-13}$  seconds. In essence it is now possible to probe the details of a chemical reaction at its most fundamental level.

He was followed by Biman Bagchi of the Indian Institute of Science, Bangalore on the "Theory of chemical reactions in the absence of a barrier". Recent picosecond and sub-picosecond laser spectroscopy experiments have revealed several chemically and biologically important reactions in solution, in which the reaction potential surface does not present a barrier to the motion along the reaction coordinate. He reported recent developments in the theoretical description of activationless processes in solution and the available experimental results.

The last series of seven lecture presentations was held in the afternoon of 9 November, under the chairmanship of Prof. E S Raja Gopal.

R Balasubramanian of the Institute of Mathematical Sciences, Madras first spoke on "Some problems in Riemann-Zeta function". He was followed by S K Gupta of the Indian Institute of Technology, Kanpur on "Unequal reactivity condensation polymerizations".

The next speaker was J A Sekhar, Defence Metallurgical Research Laboratory, Hyderabad on "The stability of solidification microstructures".

H M Antia of the Tata Institute of Fundamental Research, Bombay spoke on "Solar seismology". Ever since the discovery of solar oscillations in 1960, attempts to unravel the nature of these intricate velocity fields, have shown that the observed oscillatory velocity pattern at the solar surface is a result of the superposition of some ten million different normal modes of oscillations in the deep solar interior, each with a surface amplitude of the order of 10 cm/s. These oscillations have been observed at the solar surface as a Doppler shift of spectral lines. A careful analysis of the frequencies of these seismic disturbances of the Sun, much like those of the Earth, affords the possibility of studying the internal structure and dynamics of the Sun, to estimate the depth of the convection zone and the primordial helium abundance as well as the variation of sound speed and rotation velocity throughout most of the solar interior.

S N Tandon, also of TIFR, Bombay, spoke on "Studying star formation through infrared". The life span of a star depends on its mass and for a star, more than ten times as massive as the Sun, it could be as small as ten million years. Thus, during the billions of years of Earth's life, several generations of such stars must have been born in the Galaxy to which our solar system belongs. Young stars of various kinds are often found in groups near the clouds of molecular gas and dust distributed in the Galaxy, and these clouds (which have typical dimensions of several light years and may carry a total mass up to a hundred thousand solar masses) are thought to be sites of star formation. A one metre size balloon-borne telescope, capable of pointing to a stability of better than one third of a

minute of arc, has been used by TIFR for mapping the emission of several star-forming regions in the 120–300  $\mu\text{m}$  wavelength band. In the Carina Nebula, for example, where about one third of a square degree was mapped by the telescope, more than twenty clumps were detected near the boundaries of the ionised hot gas, each having a luminosity more than a thousand times that of the Sun. This region, situated about eight thousand light years away, appears to be forming a relatively larger proportion of heavy stars. Other clusters of young stars also show a relative deficiency of stars with masses less than a few solar masses.

The next talk was by A Suroli of the Indian Institute of Science, Bangalore on "The elucidation of the anti-*T* specificity of *Artocarpus integrifolia* and the lectin subunit heterogeneity in the molecule". The Thomsen-Friedenreich (*T*) antigen is a tumour-associated antigen of non-oncofetal origin and is probably one of the few chemically well-defined antigens with a proven link to malignancy; therefore, anti-*T* probes have an enormous potential in cancer research. Thermodynamic analysis of ligand binding to *Artocarpus* lectin together with their minimum energy conformations, which has shown that this lectin has an exquisite specificity for *t*-antigen, should make *Artocarpus* lectin a valuable probe for monitoring the expression of *T*-antigen on the cell-surfaces.

The last speaker was Anil Kumar, also of the Indian Institute of Science, Bangalore, who spoke on "Two-dimensional NMR spectroscopy". In two-dimensional NMR spectroscopy, the response of a spin system to two or more impulses is recorded as a function of two time variables yielding, on double Fourier transformation, a spectrum, which is extremely rich in information content. As a result, two-dimensional spectroscopy has had a revolutionary effect on the NMR study of biomolecules.

The Meeting ended at 1800 hours on 9 November with concluding remarks by the President.

There was a dance recital by Padma Subramanyam on Saturday 7 November in the Tagore Auditorium in the Osmania University Campus.

The Academy is grateful to the Regional Research Laboratory, the National Geophysical Research Institute, the National Institute of Nutrition and to the Local Organising Committee, particularly to Dr A V Rama Rao, Director, RRL, for the organisation of the Annual Meeting. Our special thanks are due to Prof. T V Ramakrishnan and Dr A V Rama Rao for the organisation of the two specialized symposia.

The 53rd Annual Meeting was attended by 123 Fellows and 20 Associates. The group photograph taken on the occasion is reproduced on pages 12 & 13.

# Raman Centenary

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1988 is the birth centenary of Prof. Sir C V Raman. The diamond Jubilee of the discovery of Raman Effect also falls in 1988. The major responsibility for celebrating this event has been undertaken by the Indian Association for the Cultivation of Science, Calcutta, for it was in the laboratories of this Association that Raman's famous discovery was made. The formal celebrations will be from 2–6 November 1988, when an International Conference on Raman Spectroscopy will be held to commemorate both the birth centenary of Professor C V Raman and the diamond jubilee of the discovery of the Raman Effect. These will be organized by the Indian Association for the Cultivation of Science jointly with the Indian Academy of Sciences and the Indian National Science Academy. The topics will include the latest advances in the following areas: resonance Raman and excited states, CARS, SERS, Raman spectroscopy of solid state and biological systems, time-resolved spectroscopy, new Raman techniques etc..

As announced earlier, the Indian Association for the Cultivation of Science has invited the Academy to hold its 54th Annual Meeting at Calcutta. The Annual Meeting will be held immediately after the formal celebrations at Calcutta, so that Fellows who attend the Annual Meeting can also participate in the programme organised by the Indian Association for the Cultivation of Science.

The scientific programme of the Annual Meeting is now being finalised by the Council of the Academy.

A biography of Prof. C V Raman by G Venkataraman, to be published jointly by the Indian Academy of Sciences and the Indian National Science Academy, will be released during this period. The Academy will also publish in 1988 four more volumes of the Collected Papers of C V Raman on Acoustics, Optics, Colour and Crystal Physics. Raman's Collected Papers on 'Scattering of Light' which were published in 1978, are also being reprinted.

# Early Days of Quantum Mechanics

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Academy lecture given by Prof. Rudolf Peierls on "Recollections of the early days of quantum mechanics – more about physicists than about physics" at the Indian Institute of Science, Bangalore on 26 November 1987.

*Prof. S Ramaseshan introduced the speaker as follows:*

Rudolf Peierls' name has become an integral part of modern physics. Every problem he has touched he has embellished, whether it be in statistical physics, condensed matter physics or nuclear physics. Each of his contributions is seminal and has set the directions for the future. For example, his work with Landau on the nature and long range order in one-dimensional and two-dimensional systems, was done decades before it was applied to liquid crystals. Or his work with Bethe on short range order in phase transitions. This was generalized and applied much beyond its original context. The problems in quantum theory which he has worked on – indeed the panorama of problems he has taken up, is really breathtaking.

There are even more significant aspects of Prof. Peierls' standing amongst his peers. His book on *Quantum Theory of Solids* is the kind that other writers of books and of papers have to consult to be sure that they have got everything right. The nine volumes of Landau and Lifshitz form the Bible for many theoretical physicists. To be repeatedly cited in this work is the closest one can come to canonisation. Peierls has been so cited. This to me is much better than a long list of medals and honours which also he has.

On a personal note, some of us at the Raman Research Institute consulted him on the scattering of positrons by hydrogen atoms with the formation of positronium. It was a lesson and it was a pleasure to watch the maestro at work, reducing the problem to its bare essentials and formulating a scheme of calculations which captured the physics of the problem.

It has been a privilege to be with him, listening to his incomparable science and incomparable stories. For example, he told me the story of the great Rutherford's letter to Niels Bohr about his painful knee which had just healed. Rutherford, who was known to have driven his students wrote:– "The pain has gone. I can now kick my

students with pleasure — and not with a feeling of painful duty”.

It is not too well known that Rudolf Peierls applied for a position at the Institute in 1933 or 1934 when he was 26 or 27. Raman tried to support the older Max Born; that too was in vain. If Rudolf Peierls had come, it would have been good for the Indian Institute of Science, good for Indian physics, but one is not too sure whether it would have been good for Rudolf Peierls. Would he have met all the physicists about whom he is going to talk today?

In the preface of his book, *Bird of Passage*, Sir Rudolf tells us how Zuchichi told him: — “You are getting on in years. You must have known many physicists that we only read about. Could you not tell us about them?”. This is how the delightful book “*Bird of Passage*” was begun. Just as he is writing an enlarged second version of his now famous “*Surprises in Theoretical Physics*”, we should persuade him to write a second version of his “*Bird of Passage*”.

Ladies and Gentlemen I present Sir Rudolf Peierls — the physicist’s physicist — to tell us about physicists.

*A summary of the lecture follows:*

One of the most exciting periods in the growth of modern physics was from 1924 to 1930 during which the fundamental ideas and applications of quantum mechanics were developed. Prof. Rudolf Peierls, who studied and worked during these years at Berlin, Munich, Leipzig, Copenhagen, Zurich, Rome and Cambridge, was both a witness to this period of explosive growth, as well as a participant in it and his Academy lecture was about the legendary figures involved — Planck, Sommerfeld, Heisenberg, Pauli, Fermi, Bohr and Dirac to name some of them.

These men differed in almost every possible way in their personalities, style of research, and dealings with their fellow men. For example, Sommerfeld emerged as a masterly teacher with interests in all areas of physics, and a powerful mathematical bent. In contrast, Heisenberg had more strongly focussed interests and would first attack a problem by intuition before resorting to mathematics. While the first was strongly conscious of his dignity and status as a professor, the second could easily be taken for an average man in the street.

Thanks to his professors (Sommerfeld and then Heisenberg) taking sabbatical leave to go to the United States, young Peierls moved from Munich to Leipzig and then to Zürich, where he worked with Pauli. Apparently Pauli was famous for

working late into the night and sleeping late. On being told of a seminar at nine in the morning, he remarked that he could not stay up that late! An enigmatic aspect of his personality was his deep criticism usually expressed in a most abrasive fashion. Apparently even Einstein was not immune from his sharp remarks but one consolation was that he applied the same severe standards to himself. It was at Zürich that Peierls met Landau, whose style of studying papers was to read the conclusions and derive them for himself!

Copenhagen was a great centre for those working on the quantum theory — thanks to Niels Bohr. His deep critical faculty showed itself in repeated revisions of his manuscripts, which started out as clear and easy to understand but evolved with addition of various qualifications to the point of obscurity.

A timely Rockefeller fellowship made visits to Rome and Cambridge — and hence to Fermi and Dirac — possible. It appears that Fermi avoided complex calculations and tended to set a problem aside if it led to them. Needless to say, his ability to find simple ways of doing most problems was far greater than most people’s. It was here that Peierls encountered the usefulness of numerical methods — something which has now become a part of modern physics.

While many accounts of this era have been written, it will be difficult to find one which matches this lecture for its humour, unassuming attitude and authenticity. The many slides of informal moments, usually on the beach or in the mountains, enhanced the vivid portrayal of those times.

# Honorary Fellows elected in 1987

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**Richard Askey**, Department of Mathematics,  
University of Wisconsin-Madison, Madison, USA.

**Seymour Benzer**, Division of Biology, California  
Institute of Technology, Pasadena, California,  
USA.

**Abdus Salam**, International Centre for Theoretical  
Physics, Miramare, Trieste, Italy.

# Fellows elected in 1987

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**S S Abhyankar**, University of Poona, Pune, for his  
contributions to algebraic geometry.

**M K Chaudhuri**, North-Eastern Hill University,  
Shillong, for his contributions to synthetic  
inorganic chemistry.

**J Das**, Indian Institute of Chemical Biology,  
Calcutta, for his work on genetics and chemical  
biology.

**S C Dutta Roy**, Indian Institute of Technology, New  
Delhi, for his studies on signal processing.

**J Gopalakrishnan**, Indian Institute of Science,  
Bangalore, for his contributions to inorganic  
synthesis and solid state chemistry.

**M S Gopinathan**, Indian Institute of Technology,  
Madras, for his work in quantum chemistry.

**Harjit Singh**, Guru Nanak Dev University,  
Amritsar, for his studies of organic reactions and  
synthesis.

**Indira Nath**, All India Institute of Medical Sciences,  
New Delhi, for her contributions to immunology  
of leprosy.

**T Jacob John**, Christian Medical College Hospital,  
Vellore, for his work in paediatrics and virology.

**George Joseph**, Space Applications Centre,  
Ahmedabad, for his contributions to  
instrumentation and remote sensing.

**P C Kapur**, Indian Institute of Technology, Kanpur,  
for his studies of ceramic materials.

**B D Kulkarni**, National Chemical Laboratory,  
Pune, for his work in chemical reaction  
engineering.

**A S Mukherjee**, University of Calcutta, Calcutta,  
for his work on genetic aspects of development  
and repair.

**D Mukhopadhyay**, Indian School of Mines,  
Dhanbad, for his contributions to tectonics and  
stratigraphy.

**A V Narlikar**, National Physical Laboratory, New  
Delhi, for his experimental studies of  
superconductivity.

**N C Nayak**, All India Institute of Medical Sciences,  
New Delhi, for his studies of hepatitis and other  
liver diseases.

**N Panchapakesan**, University of Delhi, Delhi, for  
his contributions to quantum field theory and  
general relativity.

**R Parimala**, Tata Institute of Fundamental  
Research, Bombay, for her contributions to  
modern algebra.

**T Parthasarathy**, Indian Statistical Institute, New  
Delhi, for his studies in statistics and probability,  
especially game theory.

**J Pasupathy**, Indian Institute of Science, Bangalore,  
for his contributions to particle and nuclear  
physics.

**L M Patnaik**, Indian Institute of Science, Bangalore,  
for his contributions to computer science,  
especially distributed and parallel processing.

**J Ramachandran**, ASTRA Research Centre,  
Bangalore, for his contributions to bio-organic  
chemistry and molecular biology.

**M R Satyanarayana Rao**, Indian Institute of  
Science, Bangalore, for his work in biochemistry  
and molecular biology.

**R Shashidhar**, Raman Research Institute,  
Bangalore, for his experimental studies of the  
physics of liquid crystals.

**B S Shastry**, Tata Institute of Fundamental  
Research, Bombay, for his contributions to  
condensed matter theory, particularly exact  
solutions.

**A R Sheth**, Institute for Research in Reproduction,  
Bombay, for his work in reproductive biology.

**R N Singh**, National Geophysical Research  
Institute, Hyderabad, for his contributions to  
crustal geology.

**Sipra Guha-Mukherjee**, Jawaharlal Nehru  
University, New Delhi, for her work in  
biochemistry and morphogenesis in plants.

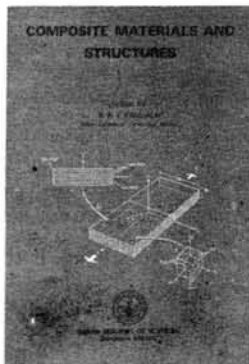
**G V Subba Rao**, Indian Institute of Technology,  
Madras, for his contributions to solid state  
chemistry and materials science.

# Special Publications

In addition to the thirty special publications described in earlier issues, the following four volumes were published during 1987–1988.

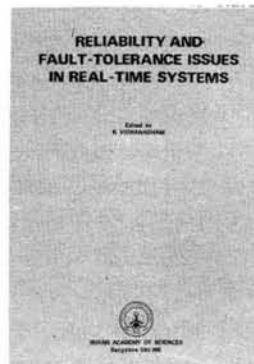
1. *Composite Materials and Structures*, Edited by K A V Pandalai, published in 1988, Price Rs.70, US \$ 30, 166 pages.

Composites are a class of materials that have revolutionized practically every sphere of industrial activity and technology during the last three decades. To focus attention on composite materials and their increasing engineering applications, an International Conference on Composite Materials and Structures was organized by the Fibre-Reinforced Plastics Research Centre of the Indian Institute of Technology, Madras in January 1988. This issue contains eleven invited papers on specific issues and problems relevant to the field of composites and which were presented at the Conference. All the 50 papers presented have been brought out as the *Proceedings of the Conference* published by Tata McGraw Hill Publishing Company. These eleven papers were also included in a special issue of *Sādhanā* (Vol. 11, 1987).



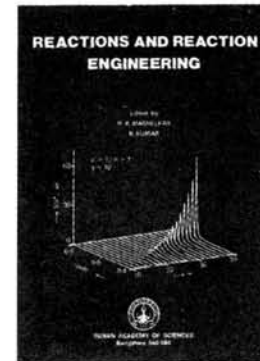
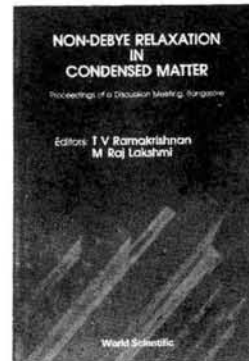
2. *Reliability and Fault-Tolerance Issues in Real-Time Systems*, Edited by N Viswanadham, published in 1987, Price Rs.90, US \$ 40, 283 pages.

With the increasing use of computers in a variety of application areas, such as control of hazardous chemical plants and nuclear reactors, in process industry, battle management and weapons delivery in defence, intensive care and diagnostic systems in health care, and control systems for air and high speed transportation, system reliability and timely fault-detection and diagnosis and system reconfigurations are vital. The design of fault-tolerant systems is a complex problem and in this volume the reliability and fault-tolerance issues in real-time computer systems is treated under four headings: fault-tolerant



software, fault-tolerant computer architectures, performance modelling of fault-tolerant systems and applications. Taken together, the fourteen papers in this volume help the reader to obtain an overall view of the design of real-time systems with specifications on reliability and fault-tolerance.

The papers have also appeared in *Sādhanā*, Vol. 11, 1987.



3. *Non-Debye Relaxation in Condensed Matter*, Edited by T V Ramakrishnan and M Raj Lakshmi, published for the Indian Academy of Sciences by World Scientific Publishing Co., Singapore in 1987, 401 pages.

This volume consists mainly of lectures given at a discussion meeting on non-Debye relaxation in condensed matter at the Indian Institute of Science, Bangalore from 14 to 17 September 1982. The meeting, sponsored jointly by the Indian Academy of Sciences, the Department of Science and Technology and the Indian Institute of Science, was aimed at focussing attention on a pattern of behaviour common to very different classes of systems. The first of its kind ever held, it covered relaxation phenomena of all kinds in materials of all types, using different techniques such as dielectric, NMR and visco-elastic relaxation measurements.

The volume contains fourteen talks, with an introduction by Prof. T V Ramakrishnan. The first talk by K L Ngai is a detailed overview of the field and is expanded here to 170 pages. The remaining papers describe relaxation in metallic and insulating glasses, disordered solids, amorphous semiconductors, spin glasses and superionic conductors. The relaxation spectra are broad and are not described by a single relaxation time (hence the name non-Debye relaxation). The entire field is in a state of active evolution and the next few years should lead to a clearer understanding of the phenomena.

4. *Reactions and Reaction Engineering*, Edited by R A Mashelkar and R Kumar, published in 1987, Price Rs 100, US \$ 40, 331 pages.

This volume was published as a special issue of *Sādhanā* in 1987, Vol. 10, Parts 1 and 2 and was described in *Patrika* 15 of July 1987.

# Special Issues of Journals

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*Surveys in Fluid Mechanics II, Sādhanā*, Vol. 10, Parts 3 and 4, pages 319–502, August 1987.

The papers collected in this volume are extended versions of invited lectures given at the Third Asian Congress of Fluid Mechanics, held in Tokyo in August 1986. A similar volume of papers from the First Congress held at Bangalore in 1982 was published in 1982 as a special publication (see *Patrika* 5).

The nine papers in this volume, although not as numerous as those in the first, again represent the spread of interest that is characteristic of fluid mechanics. The problems discussed concern transition, turbulence, fluid-dynamical models and geophysical and aerospace applications. Some important applications are also discussed.

*Trends in Theoretical Chemistry, Proceedings — Chemical Sciences*, Vol. 99, Numbers 1 and 2, August 1987.

The papers published in these Proceedings, were presented at the first National Meeting on Trends in Theoretical Chemistry, sponsored jointly by the Indian Academy of Sciences and the Panjab University, Chandigarh and held at Chandigarh from 16–18 October 1986. The purpose of the meeting was to bring together Indian theoretical chemists for intense discussions on each other's area of study, leading to an assessment of emerging problems of importance in theoretical chemistry. Among the thirtyfive participants were chemists, physicists, biophysicists and mathematicians. The topics covered include quantum chemistry, spectroscopy, scattering, relaxation, statistical mechanics and condensed phases. The issue contains seventeen of the papers presented on quantum theory and mathematical methods, quantum chemistry and quantum biology and statistical mechanics and provides a glimpse into some of the interesting areas of theoretical chemistry being studied in India.

*Biosystematics of Insects, Proceedings — Animal Sciences*, Vol. 96, Number 5, September 1987.

The multidimensional concept of species has come to occupy a predominant place in the study of life sciences and the need for an integrated approach to biosystematic studies has been recognized for some time. Biosystematics has accordingly emerged as an interdisciplinary area

of research in life sciences, with considerable impact on applied biology, in particular in the fields of agriculture, forestry, medical and veterinary sciences.

The twentyone papers published in this special issue were presented at the Workshop on Biosystematics of Insects, held at the Entomology Research Institute, Loyola College, Madras during 27–30 April 1987.

*Proceedings — Animal Sciences*, Vol. 96, Number 3, May 1987.

Nutrition and reproduction are inter-related processes occurring in the developmental biology of insects, and are of importance in arriving at a knowledge of insect-plant or parasite/predator interactions. Bioenergetic studies have shown that protein-rich food is among the principal factors influencing fecundity, the others being feeding regimes. The twenty-two papers published in this special issue cover areas such as nutritional modulation of reproduction in predatory and parasitic insects, neuro-endocrine control of insect nutrition and reproduction, as well as energy components involved and will go a long way in furthering our knowledge in this very important field of entomological research.

Among the earlier special issues of the journals devoted to special topics and published in 1986 are:

1. Prof. Sadhan Basu Festschrift (*Proceedings — Chemical Sciences*, February 1986)
2. Proceedings of the Winter Workshop on Solid State Chemistry (*Proceedings — Chemical Sciences*, April 1986)
3. Prof. K S G Doss Festschrift (*Proceedings — Chemical Sciences*, October 1986)
4. Proceedings of the UNESCO Workshop on Applied Mycological Research in the Tropics, Singapore (*Proceedings — Plant Sciences*, November 1986)
5. Dr Salim Ali Festschrift (Supplement to *Proceedings — Animal/Plant Sciences*, November 1986)
6. Fifth Generation Computer Systems (*Sādhanā*, September 1986)
7. Prof. D S Kothari Festschrift (*Pramana — Phys.*, July-August 1986)
8. Proceedings of the Symposium on Computer Modelling and Applications in Metallurgical Research and Industry (*Bulletin of Materials Science*, May 1986)
9. Proceedings of the Symposium on Thin Film Science and Technology (*Bulletin of Materials Science*, June 1986).

# Obituaries

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With the passing of **Anil Kumar Ganguly** India has lost a dedicated and active environmental scientist. He was born on November 1, 1918 at Faridpur, now in Bangladesh. After completing his school education with distinction, he joined Calcutta University, for his Bachelor's and Master's degrees in Chemistry, which he obtained in 1938 and 1940 respectively. He worked as a lecturer in chemistry at the Scottish Church College and at the University of Calcutta till 1951, during which period he also carried out research on the cation exchange in silicate minerals related to soils and clays, obtaining his D.Sc. degree in 1949.

Soon after, he joined the University of Notre Dame in USA to work with Prof. John Magee. Their joint paper in 1956 on the now famous Ganguly-Magee model, laid the foundations for our current theoretical understanding of the primary events in the interaction of high energy radiations with aqueous solutions.

On his return to India in 1956, he joined the Atomic Energy Establishment, Trombay, now BARC, first as Head of the Radiation Protection Unit and later of the Health Physics Division and finally of the Chemical Group as its Director. He encouraged freedom of expression and action among his colleagues, winning their unquestioned loyalty and respect. A benevolent and kind friend and mentor, he was loved by all those who came in contact with him.

He organized a chain of environmental survey laboratories and helped to establish standards of background radiations. He also played a key role in evolving safety criteria for siting nuclear power plants in the country.

During the last 25 years of his life, his interest centred mainly in the scientific study of the environment, atmospheric, aquatic and terrestrial. His work ranged from marine geochemistry and radiation and ultraviolet dosimetry to systematic investigations on binary nuclear fission and the evaluation of the design and siting of nuclear installations. His contributions to geochemistry include the work on humic acid and on weathering of rocks in the Western Ghats. His theoretical model, based on order-disorder phenomena, explained for the first time several characteristics of fission processes such as asymmetry, charge distribution, odd-even effects and neutron evaporation characteristics.

He also undertook developmental work on the non-destructive assay of fertile and fissile

materials, long before the International Atomic Energy Agency started work in this area. He was the founder president of the Indian Association of Radiation Protection. He was a member of the first Committee constituted by the Government of India for Environmental Coordination and as a member of the Tiwari Committee he made significant contributions for restructuring the Department of Environment.

He was the recipient of many distinctions and awards. He was elected a Fellow of the Academy in 1977. He was awarded the Padma Shri in 1974 and was a National Fellow of the Department of Science and Technology from 1978 till his death.

He passed away on 17 January 1988 at Bombay. He is survived by three sons and a daughter.

**Peter Brian Medawar** was born in Rio de Janeiro, Brazil on 28 February 1915. He was educated at Oxford, from where he graduated in 1939. From 1938 to 1944 and from 1946 to 1947 he was a Fellow of Magdalen College at Oxford and from 1944 to 1946 a Fellow of St. John's College. In 1947, he was appointed the Mason Professor of Zoology at Birmingham University and in 1951, the Jodrell Professor of Zoology and Comparative Anatomy at University College, London. In 1962, he joined the National Institute for Medical Research at Mill Hill in London as its Director. He was Head of the Division of Surgical Sciences of the Clinical Research Centre from 1971 and in 1977 joined the Royal Institution as its Professor of Experimental Medicine.

He was the most distinguished British biologist of his generation. He founded transplantation biology as a scientific study, and thus laid the cornerstone of modern immunology. His favourite experiment was to measure with meticulous precision the time taken for rejection of a skin graft. In this way he discovered that second-set grafts undergo accelerated rejection, and hence that rejection is brought about by an immunological response on the part of host lymphocytes against histocompatibility antigens in cells of the graft. This led to identification of the lymphocyte as the immunologically reactive cell, and eventually to recognition that cellular immune responses are as important as antibodies to the immune system. Having identified the mechanism of rejection, he went on to discover, in the anterior chamber of the eye and elsewhere, sites where lymphocytes do not penetrate and which therefore enjoy 'immunological privilege'.

Medawar's greatest single discovery, made jointly with Billingham and Brent, was of immunological tolerance: the immune system is

not pre-programmed to distinguish between self and non-self, but learns to do so as a result of exposure to self-molecules during early development. This principle enables us to understand how the immune system is shaped, helps establish the working of clonal selection among lymphocytes, and leads on to a rational understanding of auto-immune disease. For this work, Medawar shared the Nobel prize for medicine in 1960 with Frank Macfarlane Burnet.

The war effort and the needs of burn victims drew Medawar away from his first work, which was on the growth of embryos. He retained a strong interest in developmental biology, and his discovery with Billingham of pigment spread later persuaded him to follow the plasmagene will o' the wisp. What fascinated him was the possibility that pigmented cells might transmit into their non-pigmented neighbours self-replicating information for pigment production: but pigmentation is now known to spread only through cell movement.

As Director of the National Institute for Medical Research between 1962 and 1971, his research focussed on the development of an anti-lymphocyte serum to prevent graft rejection. After leaving the Institute he returned finally to embryos and elegantly demonstrated cross-immunity between cancer cells and fetal tissue.

Medawar was endowed with a sense of humour, a profound respect for the creative individual, and a dislike of pomposity. His own research was invariably carried out within a small, personally devoted group.

He was elected an Honorary Fellow of the Academy in 1968. He received the Royal Medal in 1959 and the Copley Medal of the Royal Society in 1969 and the Hamilton Fairby Medal of the Royal College of Physicians in 1971.

He was elected to numerous academies and societies, including the Royal Society (1949), the American Academy of Arts and Sciences (1959), the Royal College of Surgeons (1967), the U.S. National Academy of Sciences (1969) and the Royal College of Physicians (1971). He was made a Commander of the Order of the British Empire in 1958, a Knight in 1965 and a Companion of Honour in 1972. He was awarded the Order of Merit in 1981.

His interest in that area of biology, where human demography and genetics overlap, found expression in his books, *The Uniqueness of the Individual* (1956) and *The Future of Man* (1960). He also wrote *The Art of the Soluble* (1967) (now

published with other masterly essays as *Pluto's Republic*), *Induction and Intuition in Scientific Thought* (1969), *The Hope of Progress* (1972), *The Life Science: Current Ideas of Biology* with J S Medawar (1977), *Advice to a Young Scientist and the Limits of Science*.

His *An Autobiography: Memoir of a Thinking Radish*, shows that the man encountered is exceptional in all kinds of ways — a scientist of world renown, a brilliant writer on science for intelligent readers of all backgrounds, and a persistently courageous survivor of a series of major strokes and one of the most engaging and impressive men of our time.

He passed away at London on 2 October 1987.

**Robert Sanderson Mulliken**, was born on June 7, 1896 at Newburyport, Massachusetts, USA. He received his bachelor's degree in 1917 from the Massachusetts Institute of Technology, where his father was a professor of chemistry, his Ph.D in Physical Chemistry in 1921 from the University of Chicago and the Sc.D from Columbia University in 1939. From 1921 to 1925 he was National Research Council Fellow at Chicago and Harvard. It was during this period that he started his experimental work on the spectra of diatomic molecules, like BO, CO and CN, successfully identified the emitters of the band systems and explained the finer details of the band spectra. He was able to derive theoretically the molecular energy states with the aid of the then newly emerging quantum mechanics. One of his early contributions was on the isotope effect in band spectra. From a study of the isotope shifts of the bands he showed for the first time in 1924, the existence of null-point energy, even in the zero vibrational level.

He taught at New York University from 1926 to 1928, then returned to the University of Chicago, where he was Associate Professor of Physics (1928–31), Professor of Physics (1931–61) and Professor of Physics and Chemistry (1961). From 1956 to 1961, he was Ernest DeWitt Burton Distinguished Service Professor. Although formally emeritus since 1961, he continued active work as Distinguished Service Professor of Physics and Chemistry at Chicago and as Distinguished Research Professor of Chemical Physics at Florida State University, where he spent the winter months.

His major accomplishments were in the application of the principles of quantum mechanics to the problems associated with chemical bonding, such as the theory of isotope separation by evaporative centrifuging,

experimental study of diatomic and molecular spectra and the nature of electronic states of molecules, the theoretical systematization of the electronic states of molecules in terms of molecular orbitals (analogous to the atomic orbitals occupied by electrons around individual atoms) and the application of group theory to deal with electronic states of polyatomic molecules. Other contributions were his estimation of the ionic character of a bond and his studies on electronegativity and his explanation of the phenomena of hyperconjugation on the basis of quantum-mechanical considerations. In 1952 he developed a quantum-mechanical theory for the interaction of electron donor molecules with electron acceptor molecules and in particular, of the charge-transfer spectra of molecular complexes.

Mulliken considered himself a "middleman between experiment and theory" and although in later years he did not carry on experimental work himself, experimental spectroscopic work was always being carried out under his supervision in the Laboratory of Molecular Spectra and Structure. Mulliken's papers often dealt with problems on the interpretation of specific diatomic and polyatomic spectra, as well as with general related theory.

He was elected an Honorary Fellow of the Academy in 1969. He was awarded the Nobel Prize in 1966 for his fundamental work concerning chemical bonds and the electronic structure of molecules by the molecular orbital methods.

He was honoured by the American Chemical Society with the award of its Gilbert Newton Lewis Medal in 1960, Theodore William Richards Medal in 1960, the Peter Debye Award in 1963, the John G. Kirkwood Medal in 1964 and the Willard Gibbs Medal in 1965.

He passed away at Arlington, Virginia on 31 October 1986.

**Subramania Paramasivan** was born in 1903 and had his early education in Madras. He took his Master's degree and the D.Sc degree from the Madras University and worked for a few years as lecturer in chemistry at the Theosophical College, Madanapalle and as lecturer in physics at the Ananda College, Colombo. He joined as the first archaeological chemist at the Madras Government Museum, where he organised a chemical laboratory for the conservation of Indian sculptures and paintings.

He later joined the Archaeological Survey of India and again organized a chemical laboratory for the conservation of Indian wall paintings dating from the second century B.C at Ajanta, Ellora, Bagh and Tanjore.

An expert in the scientific conservation of ancient monuments and historic and artistic works, he was elected a Fellow of the Indian Academy of Sciences in 1938. He was also a Fellow of the International Institute for the Conservation of Historic and Artistic Works, London.

He initiated neutron activation analyses of ancient materials and thermoluminescence dating of ancient pottery, in the Bhabha Atomic Research Centre and in his later years did considerable work on the degradation of the environment through the ages, through a study of archaeological strata.

He passed away at Madras on 15 May 1987.

**Chunibhai Chhotabhai Patel** was born in Nadiad, Gujarat on 17 March 1920. After graduation from Wilson College, Bombay, he obtained his M.Sc and Ph.D degrees from the Indian Institute of Science, Bangalore, receiving the coveted Sudborough Medal. He later joined the faculty of the Department of Inorganic and Physical Chemistry at the Institute, where he worked till his retirement in 1980.

Patel's early work was on the novel and innovative methods in the electrolytic production of sodium hydrosulphite. He visualized very early the importance of thermal studies in the synthesis of inorganic compounds and set up a differential thermal analysis unit in the Department.

He also recognized the great utility of inorganic complexes in analytical chemistry and the study of areas such as unusual valency states of metal ions and biological systems. His contributions to coordination chemistry of transition metal ions are outstanding. He was one of the earliest workers to use spectroscopic methods to arrive at the electronic structures of novel metal complexes and his choice of ligand systems to study electronic structures of transition metal ions was remarkably original. His discovery of the triangular ring structure of the peroxy titanium group in the early sixties was mainly based on spectral studies. In later years he investigated a large number of metal complexes containing different ligating atoms.

Patel's research interests were not restricted to coordination chemistry. He took keen interest in the development of mineral chemistry and as early as 1950, investigated the chlorination reactions of indigenous ilmenite ore, to obtain chlorides of iron and titanium. His work on froth floatation of copper minerals is well known.

An outstanding inorganic chemist, he was loved and respected by his colleagues and students. Keenly interested in the Sarvodaya Movement, he took an active part in its adult education programme. He was elected a Fellow of the Academy in 1975.

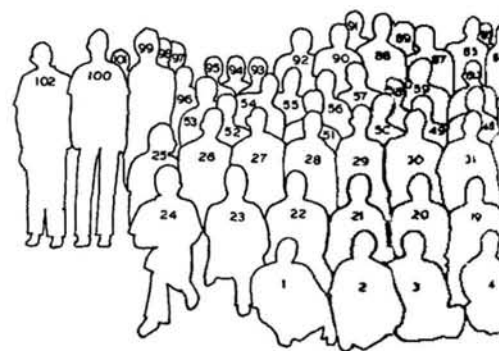
# Participants at the 53rd Annual Meeting Held at Hyderabad

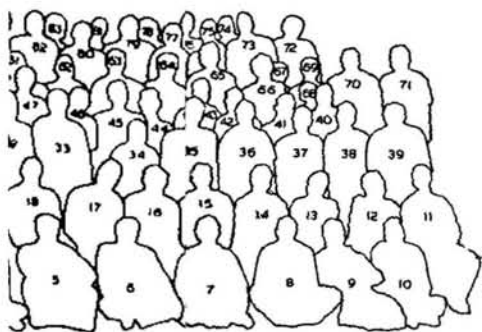


1. A. Surolia
2. P. Ramachandra Rao
3. C.L. Mehta
4. G. Madhavan
5. N. Viswanadham
6. R. Rajaraman
7. R. Nityananda
8. E.S. Raja Gopal
9. B. Bagchi
10. G.R. Desiraju
11. H. Sharat Chandra
12. A.K. Susheela
13. Anna Mani
14. S. Dhawan
15. S. Ramaseshan
16. S. Varadarajan
17. O. Siddiqi

18. A.V. Rama Rao
19. Joy David
20. H.Y. Mohan Ram
21. K. Venkateswarlu
22. D.V. Bal
23. Virendra Singh
24. V.K. Gaur
25. K.R. Parthasarathy
26. P.K. Das
27. U.W. Kenkare
28. S.S. Jha
29. A.S. Kolaskar
30. M. Venkataraman
31. S. Rangaswami
32. S.N. Tandon
33. N. Kondal Rao
34. P. Brahmayya Sastry

35. S. Sriramachari
36. Prem Narain
37. Anil Kumar
38. Rahul Pandit
39. N. Kumar
40. K.R.K. Easwaran
41. G.S. Krishna Rao
42. M.R. Raghavendra Rao
43. P.R. Adiga
44. N. Appaji Rao
45. P.R. Roy
46. C. Ambasankaran
47. P.G. Adyalkar
48. M.S. Kanungo
49. H.D. Kumar
50. R.V. Bhonsle
51. D.P. Roy





- 52. P.K. Ghosh
- 53. S.G. Dani
- 54. G. Rajasekaran
- 55. P.V. Kulkarni
- 56. B.B. Biswas
- 57. R.G. Rastogi
- 58. M.S. Valiathan
- 59. S.K. Joshi
- 60. M.S. Vardya
- 61. J.A. Sekhar
- 62. V. Baliah
- 63. P.T. Narasimhan
- 64. M.V. George
- 65. A. Chakravorty
- 66. G. Mehta
- 67. N.V. Madhusudana
- 68. G.S. Ranganath

- 69. S.K. Gupta
- 70. G. Marimuthu
- 71. M.A.L. Thathachar
- 72. D. Mukherjee
- 73. J.P. Mittal
- 74. T.A. Davis
- 75. C.J. Saldanha
- 76. T.C. Anand Kumar
- 77. N.S. Narasimhan
- 78. K.P. Gopinathan
- 79. D.V.S. Jain
- 80. N.A. Narasimham
- 81. G.P. Kalle
- 82. V. Krishnan
- 83. T.R. Kasturi
- 84. M.K. Chandrashekar
- 85. Madhav Gadgil

- 86. R. Mehrotra
- 87. B.L.K. Somayajulu
- 88. K. Gopalan
- 89. V. Radhakrishnan
- 90. U.R. Ghatak
- 91. K.S. Yajnik
- 92. B.S. Ramakrishna
- 93. S. Vasudevan
- 94. E.V. Sampathkumaran
- 95. E.D. Jemmis
- 96. J.S. Yadav
- 97. S.K. Mishra
- 98. J. Chandrasekhar
- 99. Surjit Singh
- 100. I.V. Ramanuja Rao
- 101. C. Vedamurthy
- 102. R. Ananthakrishnan

He passed away at Bangalore on 15 December 1987. He will be sadly missed by his many students, colleagues and friends.

**Malur Ramaswamiyengar Narasimha Prasad** was born on 1 May 1923, in Bangalore. He had his early education at the Central College, Bangalore and took his Ph.D. degree from Mysore University. He served for a while as a lecturer in zoology at the Central College, after which he joined the Department of Zoology, University of Wisconsin, Madison, where he took a second Ph.D degree in 1958. His groundings in modern reproductive biology and endocrinology were probably acquired there in the laboratories of Prof. R.K. Meyer and Prof. H.W. Mossman. Soon after his return to India he joined the Department of Zoology, University of Delhi and soon became the Professor and Chairman of the Department.

In his early days of research, his primary interest was in comparative endocrinology, in studying the reproductive endocrinology of seasonal breeders like the garden lizard and the palm squirrel. He also worked on the reproductive biology of the slender loris, a prosimian. He soon diverted his attention to the study of some aspects of the reproductive endocrinology of the rodents and the subhuman primates, in the hope that they would provide a means of developing newer methods of contraception. The emphasis of research in the latter years of his stay in Delhi University was in studying male reproductive physiology, in particular the epididymal maturation of sperms and general epididymal physiology of the rodent and the monkey. Using available antiandrogens in a judicious manner, he arrived at an androgen threshold hypothesis to explain different levels of androgen requirement for the maintenance of varying functions of reproductive accessory tissues. This led to his suggesting the use of the antiandrogen cyproterone acetate as a contraceptive agent in man. Though initial studies with this compound in man provided some setbacks, a modified schedule is currently being evaluated for its contraceptive efficacy in man.

Prasad joined the WHO Human Reproduction Programme in 1977 where he worked for 7 years in charge of two task forces on the development of male contraceptives and of post-coital contraceptive agents.

After retiring from WHO he worked in the Department of Biochemistry, Indian Institute of Science, Bangalore, first as a visiting scientist and later as an ICMR emeritus medical scientist till his death.

He was elected a Fellow of the Academy in 1975. He was a founder member of the

International Society of Andrology and was also the vice-president of the International Society for Research in Biology of Reproduction (1972–75). He received the J.C. Bose award of the University Grants Commission in 1975 and the FICCI award of the Indian Chamber of Commerce in 1973.

A gentle, friendly, and unassuming colleague and teacher, he was a pioneer in modern reproductive biology research in the country. He will be sadly missed by his many friends, students and admirers.

He passed away at Bangalore on 7 October 1987. He is survived by his wife, son and daughter.

**Toppur Seethapathy Subramanian** was born on 24 September 1911 in Madras. He had his early schooling in Madras and took his B.Sc degree in chemistry from the Presidency College, Madras, his Masters' degree from the Banaras Hindu University and his Ph.D degree from the University of Liverpool, working with Prof. Alexander Robertson.

He continued his researches in Liverpool as a post-doctoral fellow, working on several aspects of organic and inorganic insecticides and fungicides, and obtained his D.Sc degree from the Liverpool University. His pre-eminence in the field of insecticides was widely recognised by this time and he was appointed Reader in Organic Chemistry at the Liverpool University, which position he held till 1944. During World War II his services were loaned to the Imperial Chemical Industries, where he worked on petroleum products and discovered one of the processes of making DDT.

On his return to India, he joined as Head of the Chemistry Laboratory at the Technical Development Establishment Laboratories (TDEL) at Kanpur and later as Director. His main work was on bio-degradation of tentage materials, algicides, fungicides and insecticides, and in developing high elevation kits for forward areas, field rations etc. He also established a biochemistry branch, a physiology department and an entomology section in TDEL.

In 1957, on the invitation of Dr Vikram Sarabhai, he joined the Ahmedabad Textile Industries Research Association (ATIRA) as its Director. Cotton fibre technology became an important field of study under his guidance. He organised an operational research group to study problems in spinning, weaving, dyeing, printing and marketing.

At the invitation of the Calcutta Jute Industry, he later joined the Indian Jute Industries Research Association, Calcutta, as its Director. He

reorganized the IJIRA as a co-operative research laboratory with the CSIR and included in its activities, research in improved jute breeding and agronomy and new product development such as decorative furnishing fabrics from jute. He retired from IJIRA in 1969.

An able administrator and innovator, and a gifted speaker, greatly admired for his vast erudition, his interests ranged from science, technology, music, both Western and Indian classical, to horticulture. He passed away at Madras on 19 September 1987. He will be greatly missed by his many friends and admirers.

## A Tribute

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With the passing of Professor B S Madhavarao, the country has lost a disciplined scholar and scientist, who created and maintained a level of excellence rare in our times.

Madhavarao's research spanned six decades. His earlier work was on classical algebraic geometry and analytical dynamics. Under the influence of Max Born and in collaboration with C V Raman and Homi Bhabha, Madhavarao entered the mainstream of theoretical physics. To deal with the divergence problem in field theory, Born had introduced a nonlinear theory which received much attention as a model theory. Madhavarao wrote eight research papers and his doctoral thesis on this work. But it was Homi Bhabha's presence which spurred Madhavarao to his best and widely quoted research into relativistic wave equations. Not that Madhavarao learned from Bhabha, it was quite the other way around. Fresh from his celebrated work on the cascade theory with W Heitler and having entered the heady area of meson theory, Homi Bhabha had returned to India. The thorough understanding of matrix algebra and group representation that Madhavarao possessed, together with his effervescent curiosity and Bhabha's interest in elementary particles, produced a wealth of new scientific papers, not only by Madhavarao but also by Bhabha and others. Madhavarao did take the trouble to learn the computational techniques and physical principles behind meson scattering; but it was in the area of the algebra of matrices related to particles of higher spin that Madhavarao's real contribution lies. It is one of the indirect benefits that a young student by name Harish-Chandra, who came to study physics with Bhabha, became interested in group theory and became one of the leading mathematicians of the world.

Madhavarao kept up his interest in various areas of mathematics and mathematical physics and occasionally wrote scientific papers on them. He taught (and caused others to teach) mathematics in the Institute of Armament Studies. But he had a lifelong interest in recreational mathematics; and during his later years he was completing a book on magic squares.

He was an ardent sports enthusiast. He held high offices in many sports organizations and was a life member of the National Sports Club of India.

For a person of such eminence in science, with innumerable extracurricular activities, it is strange that he was not in an institution of research like the Indian Institute of Science, Bangalore or the Tata Institute of Fundamental Research, Bombay. It certainly was not because he was not interested. Rather than place blame on anyone, one laments the missed opportunities. He did finally become a member of the Indian Institute of Science towards the close of his life as an Associate of the Centre for Theoretical Studies.

My last recollection of him is visiting him about a year ago. Since we had not seen him in the Centre for Theoretical Studies for sometime, B R Seshachar and I went calling at his home with some foreboding of his being ill or worse.

He himself opened the door; and explained that he had hurt his foot and was therefore unable to come to Malleswaram. It seems that he was watching a hockey tournament on the television; and expressed his disapproval by kicking the television set, thus hurting his foot. We then went on to talk enthusiastically about the final chapter of his book on magic squares.

In Madhavarao we had a man of insight, ability, curiosity, creativity and discipline. I would like to hope that such people are still there amongst our academics.

— E C George Sudarshan

# The Calcutta School of Physics\*

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The ten years from July 1907 to June 1917 which preceded my joining the University of Calcutta as Palit Professor Physics afforded me numerous opportunities for studying, as an impartial and disinterested observer, the efforts made during the period in this University towards fostering higher studies and research in physics. Looking back over these ten years, one cannot fail to be struck with the genuine progress that has been achieved, and with the fact that today the Calcutta University can claim to possess a real School of Physics, the like of which certainly does not exist in any other Indian University, and which, even now, will not compare very unfavourably with those existing in the best European and American Universities. What has impressed me most is the rapidity of the progress, the position now being very different from what it was ten years ago, and this is obviously a most hopeful sign for the future.

I propose in this memorandum briefly to set out what seem to me to have been the principal features of the activities that have marked the past ten years. I may frankly state at once that a decade ago there was at Calcutta a total lack of anything that could claim to be regarded as a real centre of teaching and research in physics. No doubt, the subject figured in the curricula of the university, but the higher teaching had latterly been very weak, particularly as regards mathematical physics, and research was absolutely at a standstill. A new impetus was obviously required and it was not long in coming.

## *The Indian Association for the Cultivation of Science*

The first signs of healthy activity appeared in a purely indigenous institution, the Indian Association for the Cultivation of Science, founded many years ago by one of the most far-seeing Indians of the past generation, Dr Mahendralal Sircar, who, in some measure, had succeeded in communicating to others his profound belief in the necessity for giving Indians opportunities for engaging whole-time in the highest type of scientific work. By strenuous work Dr Sircar had succeeded in getting together by private subscription just enough money to put up a building for the institution and ensure its

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\*Memorandum-presented to the Calcutta University Commission by C V Raman, Sir Taraknath Palit Professor of Physics in the Calcutta University.

permanence. Amongst those who were most closely associated with the work of this institution and took a deep interest in its welfare I should mention particularly the Hon'ble Sir Asutosh Mookerjee, who for some years, in an honorary capacity, delivered courses of lectures on mathematical physics and higher analysis at the Association. Unfortunately, however, Dr Sircar's great efforts did not meet with all the success they merited, mainly because his appeals (repeated year after year until his death in 1904) for funds with which to endow research scholarships and professorships failed to elicit any appreciable response. Meanwhile, the only other institution at Calcutta in which research in physics was possible was staffed by "Professors of Physics" drawing extremely high emoluments in the so-called "Indian Educational Service," but who did no research and were absolutely unknown to the world of science†. It is not surprising, therefore, that for many years things were at a standstill.

My own work at Calcutta commenced in 1907 and was made possible by the special facilities put at my disposal by the present Honorary Secretary, Mr A L Sircar, who had the Laboratory kept open at very unusual hours in order that I might carry on research in the intervals of my duties as an officer of the Indian Finance Department. Gradually others were drawn in to take part in the revived activities of the Association. The success which has attended these efforts is indicated by the fact that during these ten years the Association has issued as its own publications, fourteen special Bulletins, and three volumes of Proceedings, besides regularly publishing its Annual Reports. These publications have been warmly received abroad, and the Association is now in exchange relations with about fifty learned societies and institutions in various parts of the world. Its publications have been reviewed at length in current scientific literature and quoted by foreign scientific workers in original papers and standard text books. Some idea of the reputation to which the Association has attained may be obtained from the special editorial article regarding it that appeared in "Nature" of the 3rd of May, 1917, which is reprinted as appendix A of this report.

## *The New Regulations of 1909*

The introduction of the New Regulations, which came into force in the Calcutta University in 1909, undoubtedly laid the foundation for much

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† Naturally in making this statement, I must exclude the name of Dr J C Bose, who was an experimenter of distinction. But some years prior to the date I mention Dr Bose had turned his attention to biology. The research scholars in physics paid by Government and attached to Dr Bose were apparently engaged as laboratory assistants in his biological work, as none of them ever published any original papers.

of the subsequent progress. These regulations greatly strengthened mathematical teaching in the University, and the study of physics was considerably stiffened by the greater insistence upon laboratory equipment and practical work. The standard of the B.Sc. and M.Sc. examinations was raised very considerably, and in fact the outlook as regards science teaching was completely altered for the better.

Among the activities of the time should be mentioned the readership lectures delivered under the auspices of the University by distinguished scientific workers, amongst whom may be principally mentioned Dr A Schuster and Dr G T Walker. These lectures undoubtedly stimulated interest in the study of physics, and brought home to the younger generation of the University students the fact that scientific knowledge is essentially a product of the human mind and not simply something to be found printed in books. Opportunity was also given to local men to show their capacity. I may refer here to the lectures on "Optical Theories" delivered by Dr. D.N. Mallik, which have since been published in book form by the Cambridge University Press and have been favourably reviewed in "Nature" (October 4, 1917).

#### *University College of Science*

Following this, the most significant and important steps in advance achieved were the foundation of the Sir Taraknath Palit and Sir Rashbehary Ghose Chairs\* with their attached scholarships, and the establishment of the University College of Science. These made it possible for the first time to provide for the adequate teaching of the different branches of physics and the creation of a school of research in physics. The successful fruition of the object of the donors was, however, delayed and hampered by a combination of unfortunate circumstances. The most serious cause of delay was the absence of that support from Government which alone would have made possible the speedy construction and equipment of a first-class physical laboratory for research. Such assistance could surely have been looked for in view of the fact that the University had succeeded in securing

by its own efforts a sum of about 25 lakhs Rupees from private donations as a nucleus for the establishment of the College of Science, and it was naturally a most grievous disappointment to find that such support was not forthcoming. Further causes of delay were the lawsuit on the Palit estate which made the permanency of the endowment a matter for the decision of the law courts, and the attitude of the Member for Education (Sir Harcourt Butler), who declined to permit my joining the Palit Chair until I completely resigned my permanent appointment under Government and thus jeopardized my future. In fact, it was not until July 1917, that it was possible for me formally to commence my duties in the University. The Rashbehary Ghose Professor is still detained in Germany where he was deputed for training prior to the war. Owing to the absence of the State aid which would have made the complete equipment of the College possible, and the subsequent difficulty in obtaining apparatus in consequence of the war, the formation of the Physical Laboratory was seriously hampered. In the face, however, of these serious difficulties, we have succeeded in carrying on experimental research and providing for the development of postgraduate teaching.

#### *Improvement of M.Sc. Teaching.*

The establishment of the University College of Science has made possible a great advance in the higher teaching of physics in the University. Prior to it, the only institution at Calcutta that was equipped (even in part) for M.Sc. work in physics was the Presidency College. This institution, however, had arrangements only for higher teaching in electricity, magnetism and optics and ignored all the other branches of physics, namely, heat and thermodynamics, elasticity, acoustics and general physics. Even in regard to electricity, magnetism and optics, the arrangements formerly possible were most inadequate. Practically the whole of that part of optics which has a practical application, namely, the higher theory of optical instruments and photometry, was completely ignored, and as regards the other parts of optics, no attempt appears to have been made to teach the mathematical theory in a really adequate manner. With regard to electricity and magnetism, no serious attempt was made to teach those parts of the theory that have a close bearing on technical applications of the subject. These deficiencies were in great measure due to paucity of staff and equipment, and it is precisely here that the University College of Science has come in to fill the gap. Under the new

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\* The duties of the Palit Professor are the following:

- (1) To devote himself to original research in his subject with a view to extend the bounds of knowledge.
- (2) To stimulate and guide research by advanced students in his special subject and generally to assist such students in post-graduate study and research.
- (3) To superintend the formation and maintenance of the laboratory of the College of Science in his subject. According to the special terms of his appointment, the Palit Professor of Physics is under no obligation to take any share in the teaching of M.A. and M.Sc. classes.

arrangements, the higher teaching of physics has been divided up between the combined staffs of the University College of Science and the Presidency College, and the resulting substantial addition to the number of men engaged on the work, and the high qualifications of the men attached to the University College have made a greater degree of specialization and a wider choice of subjects possible.

One respect in which the most substantial advance has been effected is in the teaching of the mathematical aspects of the different branches of physics. This is now possible, because three out of the eight lecturers in physics attached to the University College of Science are men who are first class M.Sc.s in applied mathematics, and have since made a special study of physics. Provision has also been made for teaching the different branches of physics formerly ignored, special attention being now paid to those that have the closest connection with technological practice. I have given in appendix B\* a list of the lecturers attached to the University College showing their academic qualifications. It will be seen that every one of these men has had the highest or nearly the highest University distinctions in his subject and year, and that a considerable proportion are men who have distinguished themselves by success in research. It must be obvious to every unprejudiced inquirer that the teaching of physics conducted by men of this stamp cannot possibly be much inferior to the best obtainable in any country. I would invite reference to the list of the courses of lectures in physics and the syllabuses prepared by the lecturers in different subjects. These have been printed by the University for circulation amongst the students, and a close scrutiny of the syllabuses will most clearly confirm and emphasise the facts referred to above.

#### Research Work

As might have been expected, the foundation of the Palit and Rashbehary Ghose Chairs of Physics and of the attached scholarships has also led to a great expansion of original research in Calcutta. In fact, it may now be fairly claimed that the research papers published by myself and by the researchers working in my laboratory cover much ground, and that an organisation for original research of the highest type in Physics has been firmly established in the Calcutta University. In support of this statement, I give in appendix C\* a list of twenty five papers contributed by this school during the last three years, most of which have

been published or have been accepted for publication in the best known and most widely circulated scientific journals in the English language, namely, the *L E and D*, *Philosophical Magazine*, *Nature* and the *Physical Review*. I have also added summaries of some of these papers to enable their importance to be appreciated. The list contained in Appendix C is very far indeed from completely representing all the work that has been turned out at my laboratory during the period considered, as I have not mentioned in it an extensive monograph on the acoustics of musical instruments of the violin family extending to about 200 pages in print (with thirty full-page photographic plates and a very large number of drawings) that represents a part of the original work which has been carried on by me personally during the past three years in the intervals of other duties. This monograph will shortly be issued by the Indian Association for the Cultivation of Science. Other investigations not mentioned in Appendix C are also in progress in my laboratory. In Appendix D\*, I give a list of five physical papers published by other members of the Calcutta University staff in this period.

The most encouraging sign about the new School of Physics at Calcutta is the extent to which the men who take part in post-graduate teaching actively interest themselves in research work, and this feature would have been more marked but for the fact that the physical laboratory of the University College is still in its formative stage, and some of the best men in it have their hands full with the administrative detail of laboratory organization. Four out of the eight lecturers in physics attached to the University College, namely, Mr S K Banerjee, Mr S K Mitra, Mr M N Shaha and Mr S N Basu, have succeeded in publishing research papers in European journals, and two of the others have investigations in progress which are likely to prove fruitful in the near future. Mr S K Banerjee has in particular distinguished himself by his exemplary character and by his remarkable capacity in the fields of mathematical and experimental research. In the course of about three years, he has already published six original papers, and has two more practically ready for publication. In recognition of his work, he has been awarded the Premchand Roychand Scholarship which of late years has grown to be one of the highest distinctions open to an alumnus of the Calcutta University. Mr Banerjee's papers have attracted attention in Europe, and among those who have expressed their interest may be mentioned Prof. E H Barton, FRS and Prof. J H Vincent, both of whom are well-known for their original investigations. Prof. Vincent wrote an account of Mr Banerjee's work specially for the journal *Knowledge*, and

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\* The reader is referred to the original report for appendices A, B, C and D.

Prof. Barton in reviewing Mr Banerjee's work in *Science Abstracts* suggested that the instrument devised by him and used in his work should be given the name of *Ballistic Phonometer*. I venture to think that in Mr S K Banerjee, the Calcutta University possesses a man who can claim to be regarded as a rising young researcher of the best type. Mr S K Mitra has also shown most praiseworthy ability and industry and is a researcher of great promise.

I wish also to draw pointed attention to the fact that appears from the appendices C and D, that a wide range of subjects is at present attracting the attention of the Calcutta School of Physicists. General physics, acoustics, optics, electromagnetic theory, electric discharge, spectroscopy, X-rays, and resonance radiation, and radioactivity have all come in for a share of attention, and this wide range of interest will become even more manifest when our equipment is more complete, and I have had time to take on a large number of research workers and train them up. A more voluminous output may also be expected in the near future. Perhaps the most significant tributes to the fact that we have now a real scientific atmosphere at Calcutta are the numerous requests that I have received from teachers and scholars in various parts of India and Burma to be permitted to work in my laboratory and to carry on research. Such requests have been naturally complied with as far as possible, and I have now working in my laboratory an exceptionally capable young man from Madras, Mr T K Chinmayanandam, who has already given signal proof of his originality by accomplished research (appendix C). Others worked in my laboratory for short periods (during vacations and the like), but this is naturally a less satisfactory arrangement.

#### *The Calcutta Physical Society*

In order further to stimulate research in physics, and to afford post-graduate students the fullest opportunities to acquaint themselves with the original investigations in progress, it has been arranged to organize a special society with its headquarters at the University College of Science and devoted to the advancement of higher study and research in the subject. In response to an appeal issued over my signature, about eighty replies have been received from teachers of science and others living in various parts of India expressing their sympathy with the proposal and agreeing to become foundation members of the Calcutta Physical Society. Among those who have responded to my appeal, I may mention the names of such distinguished savants as Dr G C Simpson,

FRS and Mr J Evershed, M.A., F.R.S., both of the Indian Meteorological Department. The society will be soon inaugurated and there is every reason to believe that it will serve a most useful purpose.

#### *Our Most Urgent Needs*

In the preceding paragraphs, I have set out in as brief a manner as possible the present state of affairs in regard to the higher study of physics in the Calcutta University. I wish now to draw attention to a few of what I consider to be the most urgent needs of the Department of Physics in this University. First and foremost, I would put the necessity for further equipping the laboratories of the University College of Science so as to give the fullest possible scope for the development of the Calcutta School of Physics. We are doing all we can with the resources at our disposal, but if we are not to be left hopelessly behind in the great struggle for scientific progress that will arise when the war is over, it is necessary that we should begin now to prepare ourselves for it in every possible way. And I feel sure that any help that is afforded to us now will repay itself many-fold in due course of time. The second great need to which I wish to draw attention is the provision of residential accommodation in the premises of the University College of Science for the professors and staff engaged in research work. Such provision is in my opinion indispensable, if the best possible use is to be made of the time at the disposal of the workers. The third urgent need is the enlargement of the careers open to our workers. One way in which this could be achieved is that Government should show a sympathetic attitude towards our workers by recognising their proved merits and satisfying their just claims for admission into its educational and scientific services. To most men, the knowledge of the degree of recognition that awaits successful work is a stimulus not to be despised.

# The Life and Work of Srinivasa Ramanujan

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Summary of an evening lecture given by Professor K G Ramanathan at the 53rd Annual Meeting of the Academy at Hyderabad on 7 November 1987.

Srinivasa Ramanujan was born at Erode on December 22, 1887, into a poor, orthodox South Indian Brahmin family. His father, Srinivasa Iyengar, was a clerk in a cloth merchant's shop in Kumbakonam, earning Rs. 20/ per month. Ramanujan was the first child in the family, born some years after the parents' marriage, and followed later by two more sons. Ramanujan was affectionately called Chinnaswami or "Little Lord" in the family.

In 1882 at the age of five, Ramanujan entered an elementary school in town. He was shy and lonely, with a quiet and meditative nature; he preferred to watch from his window while other children played. Even at this young age, those around him were struck by his extraordinary memory and powers of concentration.

In 1895 he entered the Town High School in Kumbakonam which had a high reputation in the whole of Tanjore district. At age ten, he stood first in the district in the Primary Examination, thus winning a half-fee concession for school. He consistently came first in class, winning prize books in English Literature for his scores in mathematics. His final success in the accepted and conventional Indian academic sense was when he passed the High School matriculation examination of Madras University in 1903 in First Class with distinction. Based on his remarkable performance in mathematics and with his mother arguing for him with the College Principal, Ramanujan won the Subrahmanyam Scholarship to study in the First Year Intermediate class of the two year Faculty of Arts course at the Government College, Kumbakonam.

All through his High School years, Ramanujan had astonished everyone with his amazing mathematical gifts. He could give the values of numbers like  $\sqrt{2}$ ,  $e$ ,  $\pi$  to a very large number of decimal places. At the age of twelve, when he was in the Third Form, he had learned trigonometry all by himself. When the well-known second volume of S L Loney on the subject came into his hands,

from a neighbour who was a B A student, he solved all the problems in the book on his own. Ramanujan also developed himself the expressions for the sine and cosine functions in terms of exponentials, which are attributed to Euler in the 18th century.

A momentous event occurred in 1903, when he was just over 15 years old and in the Sixth Form or final year of High School. At this time a friend of his brought for him a book from the Government College Library, the *Synopsis of Elementary Results in Pure Mathematics* by G S Carr, a Cambridge tutor and coach, which listed more than six thousand formulae, but with practically no proofs at all. As G H Hardy says, "The book is not in any sense a great one, but Ramanujan has made it famous". The formulae covered many topics including continued fraction expressions for hypergeometric functions, geometric series, theorems on elliptic integrals, and so forth. Ramanujan set about verifying them all unaided, and also generalised many of them to find new results.

When he entered the Government College of Kumbakonam in 1904, he had no interest in and no time for anything but mathematics. So, while he scored full marks in mathematics, he failed in English and the FA course and lost the scholarship too.

Disappointed and dejected, Ramanujan ran away from Kumbakonam for a while. On returning to the college, he appeared for the FA examination as a private candidate but failed. He then made it to Pachaiyappa's College in Madras in 1906. But he continued to fail in all subjects other than mathematics because he had no time for them. He fell ill, came back to Kumbakonam, and in December 1907 he appeared again for the F.A. examination and failed. Thus the struggle between Ramanujan and what Hardy later called the "inefficient and inelastic educational system" ended in a decisive victory for the latter.

Ramanujan was now twenty and in need of some kind of employment. He tried to get a tutorship in mathematics among friends in Madras, but without success. His passion and work in mathematics, however, kept going at the highest level. Sometime in 1907, if not earlier, Ramanujan started recording his results in the first of three famous Notebooks, following Carr's style of just stating results but not indicating derivations or proofs at all.

In 1909, Ramanujan married nine year old Janaki, daughter of Rangaswami Iyengar. The need for a job became ever more urgent. In 1910, Ramanujan went to Tirukoilur to meet the Deputy Collector V Ramaswami Iyer who had founded the Indian Mathematical Society in 1907. Realising

that Ramanujan's genius would be wasted in a small taluk office, he sent Ramanujan to P V Seshu Iyer, Principal of the Government College at Kumbakonam, who managed to get for Ramanujan a temporary job in the Accountant General's Office in Madras, on Rs. 20/- a month. When this terminated, Ramanujan managed for a short while to earn a living giving private tuitions in mathematics.

At this stage, to try and make more permanent and satisfactory arrangements, Seshu Iyer sent Ramanujan with a letter to Dewan Bahadur R Ramachandra Rao, Collector of Nellore District and Secretary of the Indian Mathematical Society. Mr Ramachandra Rao realised Ramanujan's genius when he saw the results on elliptic integrals, hypergeometric series and the new theory of divergent series. "He never craved for any distinction. He wanted leisure; in other words, that simple food should be provided for him without exertion on his part and that he should be allowed to dream on .... He said he wanted a pittance to live on so that he might pursue his researches".

Ramachandra Rao offered to support Ramanujan in Madras and to pay for all his expenses, which he did for about a year. But Ramanujan could not accept such an arrangement for long. Efforts to get him a University Scholarship failed. Rao then wrote to Sir Francis Spring, Chairman of the Madras Port Trust, and Seshu Iyer introduced him to S Narayana Iyer, Manager at the Port Trust and Assistant Secretary, Treasurer and Joint Journal Editor at the Indian Mathematical Society. These twin efforts succeeded and on February 9, 1912, Ramanujan accepted the post of a Class III Grade IV Clerk in the Madras Port Trust on a salary of Rs. 30/- per month.

This was the first turning point. While working at the Port Trust, Ramanujan continued his researches at a tremendous pace. The relationship between him and Narayana Iyer, his boss, must have been an especially warm one. They often worked together on two big slates late into the night, upstairs in Narayana Iyer's home. Ramanujan frequently woke up in the middle of the night to jot down results which he said he had worked out in his dreams.

At the Port Trust too he used every available scrap of paper to do his calculations and record his results. Slowly but surely now, Ramanujan's abilities and achievements began to be noticed by those around him. In December 1911, a few months before the Port Trust job, his first major paper on "Some properties of Bernoulli's numbers" had appeared in the Journal of the Indian Mathematical Society. This attracted the

attention of C L T Griffiths, Professor at the Madras Engineering College, who was moved to write to Sir Francis Spring: "... You have in your office a young man named S Ramanujan who is a most remarkable mathematician ..... I hope that you will see that he is kept happily employed until something can be done to make use of his extraordinary gifts..."

Sir Gilbert Walker, then Director General of Observatories wrote to the Registrar of the Madras University, Francis Dewsbury, on February 2, 1913 to say: "... I have the honour to draw your attention to the case of S Ramanujan.... (I) was yesterday shown some of his work in the presence of Sir Francis Spring. He is ... 22 years of age and the character of the work ... impressed me as comparable ... with that of a mathematical fellow in a Cambridge college... It was perfectly clear to me that the University would be justified in enabling S Ramanujan for a few years at least to spend the whole of his time on Mathematics, without any anxiety as to his livelihood..." The University rose to the occasion and awarded Ramanujan a research scholarship for two years at Rs 75/- per month. That such a scholarship could have been given to someone without a degree is unimaginable today and does great credit to all those involved. The Port Trust granted him two years leave of absence, and from May 1, 1913, Ramanujan became, and remained to the end of his life, a professional mathematician fully devoted to research.

A few months before this, at the suggestion of Seshu Iyer and others, Ramanujan had written to G H Hardy, a renowned mathematician at Trinity College in Cambridge. His first letter, dated January 16, 1913, listed some 120 theorems, without proof, on hypergeometric series, definite integrals, continued fractions, asymptotic formulae and other topics. In the letter Ramanujan had written "... I had no University education but I have undergone the ordinary school course. After leaving school I have been employing the spare time at my disposal to work at mathematics... I am striking out a new path. I would request you to go through the enclosed papers. Being poor, if you are convinced that there is anything of value, I would like to have my theorems published. I have not given the actual investigations nor the expressions that I get; but I have indicated the lines on which I proceed. Being inexperienced, I would very highly value any advice you give me...". It was this letter that led to one of the most famous collaborations in the history of mathematics. Hardy's reaction is beautifully captured in his Harvard Tercentenary Lectures of 1937 as well as in C P Snow's account.

"... One morning early in 1913 he found .. large untidy envelope decorated with Indian stamps..."

he found sheets of paper... on which were line after line of symbols. Hardy glanced at them without enthusiasm... The script appeared to consist of theorems, most of them wild or fantastic looking... there were no proofs of any kind. It seemed like a curious kind of fraud.. That particular day, though, ... internally things were not going according to plan. At the back of his mind,... the Indian manuscript nagged away... A fraud or genius?... Back in his rooms at Trinity, he had another look at the script. He sent word to Littlewood... that they must have a discussion after hall... by nine O' clock or so they were in one of Hardy's rooms, with the manuscript stretched out in front of them... Apparently it did not take them long. Before midnight they knew, and knew for certain. The writer of these manuscripts was a man of genius... It was only later that Hardy decided that Ramanujan was, in terms of natural mathematical genius, in the class of Gauss and Euler...".

Hardy replied to Ramanujan on February 8, 1913. "... I was exceedingly interested in your letter and by the theorems which you state. You will however understand that before I can judge properly of the value of what you have done it is essential that I should see proofs of some of your assertions.... You will understand that, in this theory, *everything* depends on rigorous exactitude of proof... If you have made sound and independent proofs of them, it would be, in my opinion, a very remarkable achievement... I hope very much that you will send me *as quickly as possible*... a few of your proofs.... Hoping to hear from you again as soon as possible, I am, Yours very truly, G H Hardy."

Hardy had written to Sir Gilbert Walker and others to see to it that congenial conditions were created for Ramanujan's work and was determined that every effort must be made to get Ramanujan to Cambridge. On hearing from Hardy, Ramanujan was much encouraged. "... I have found a friend in you who views my labours sympathetically. This is already some encouragement to me to proceed... To preserve my brains, I want food and this is now my first consideration...".

Hardy's first attempt to persuade Ramanujan to come to Cambridge did not succeed because Ramanujan himself was reluctant. However, Hardy would not give up so easily.

E H Neville, a colleague of Hardy at Trinity College, visited Madras to deliver a course of lectures. He was asked by Hardy to see to it that Ramanujan gave up his objections to come to Cambridge. While by now Ramanujan had been persuaded to change his mind, his mother would not consent. Fortunately an unusual dream made

her change her mind; she too relented and Ramanujan prepared to leave for Cambridge. On this occasion, Neville wrote to Dewsbury, the University Registrar: "... The discovery of the genius of S Ramanujan of Madras promises to be the most interesting event of our time in the mathematical world... I see no reason to doubt that... his name will become one of the greatest in the history of mathematics, and the University and the city of Madras will be proud to have assisted in his passage from obscurity to fame".

Once again the University rose to the occasion by giving financial help. A scholarship of £ 250/- a year for two years, tenable in England, plus travel and outfit, were made available. Ramanujan sailed from Madras on March 17, 1914 and reached Cambridge on April 18, 1914.

The next three years in Cambridge were among the happiest and most productive in Ramanujan's life. He was among people who could appreciate, communicate and collaborate with him in the true sense. He attended some lecture courses, and worked extremely hard. At times he would work for upto 30 hours at a stretch, then sleep for 20. Being a strict vegetarian, he cooked his food in his own rooms, and never ate in the Trinity College Hall. While Hardy tried to teach him some of the modern mathematics he had missed, it could not be carried too far since, as Hardy says, *he* learned much more from Ramanujan. Moreover, "... he was showing me half a dozen or more new theorems each day". Along the way, in March 1916, Trinity College awarded him the B.A. degree by research.

It was during his Cambridge years that Ramanujan wrote some 27 of his 37 papers, 7 of them with Hardy. Some of the topics were new and had not been dealt with in his Notebooks; and many of the papers, in Hardy's phrase, were in the Bradman class.

However, the stresses and strains of living alone, in a cold climate, with strict food habits and in the midst of war-time privations, took their toll, and in early 1917 Ramanujan fell seriously ill. For the next two years, till he left for India in early 1919, most of the time was spent in nursing homes and sanatoria in Wells, Matlock and London. It was originally thought that he was suffering from tuberculosis, then blood poisoning, but the consensus now seems to be that it was a case of severe Vitamin B-12 deficiency, possibly caused by diet problems. The long periods of isolation in bed affected his mental state as well. A contributing factor may have been his realisation that so much of what he had done on his own before reaching Cambridge had been rediscovery of European

published them recently under the title "Lost Notebook" as a collection of about 140 unlabelled pages with some 650 formulae, on continued fractions, q-series and on what Ramanujan called mock-theta functions; many of the proofs have now been supplied by Andrews.

Ramanujan's work was mainly in the following areas: asymptotic expansions; hypergeometric series; definite integrals; elliptic functions; continued fractions; the theory of partitions; his famous function  $\tau(n)$  and modular forms; analytic number theory; and combinatorial number theory. Probably the most widely known is his work with Hardy on the partition function  $p(n)$ , the number of ways in which a positive integer  $n$  can be expressed as the sum of unordered positive integers. Before Ramanujan, no one seems to have dared or dreamt of asking.

The Hardy-Ramanujan formula is truly a high point in mathematics, a unique combination of Ramanujan's fantastic intuition and insight with Hardy's power of analysis and mathematical finesse. The new method that their work led to is called the Circle Method and is one of the most powerful tools in analytic number theory.

Ramanujan's work on  $\tau(n)$  is related to what are called modular forms and it is his results in this area that have been found to be crucial in the theory of strings being developed by high energy physicists today.

Ramanujan and Hardy's work on highly composite or "round" numbers led to probabilistic number theory, and has been found to be of importance to cryptography. The famous Rogers-Ramanujan identities were guessed by Ramanujan. Ramanujan's rediscovery of them in 1913 brought fame also to Rogers who had proved them in 1894, and the two together presented new proofs in 1919. More recently, these same identities were rediscovered by the physicist R J Baxter in Australia, while working on a problem in statistical mechanics, and very recently Andrews and Baxter have given what they call a motivated proof of these identities.

There were many who recognised Ramanujan's genius and helped him to the extent they could: P V Seshu Iyer, R Ramachandra Rao, and S Narayana Iyer in the early phase in India; then Francis Spring, Gilbert Walker, Dewsbury, Neville and Hardy in the next phase including the stay in Cambridge. We have now to thank Richard Askey, G E Andrews and Bruce Berndt for their magnificent efforts to organize and present Ramanujan's work. But of them all, it is to Hardy that we owe the greatest gratitude. If it were not for Hardy, Ramanujan would have died unhonoured

and unsung. One has only to read Hardy's lecture at the Harvard Tercentenary to realize how much he loved, admired and respected Ramanujan.

On a score of 100, Hardy gave himself 25 points; Littlewood got 30 points; the great Hilbert merited 80; but only Ramanujan scored 100. Selberg said recently: "Only in decades to come, if not longer, will we ever know the full impact of Ramanujan's mathematics and be able to understand him... Ramanujan had an uncanny skill for manipulations unequalled by anyone in history". And Littlewood, "There is hardly a field of formulae, except that of classical number theory, that he has not enriched, and in which he has not revealed unsuspected possibilities".

As Neville said: "Srinivasa Ramanujan was a mathematician so great that his name transcends jealousies, the one superlatively great mathematician whom India has produced in the last thousand years".