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THE INSTITUTE OF MATHEMATICAL SCIENCE

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1989 - 90

THE INSTITUTE OF MATHEMATICAL SCIENCES

ANNUAL REPORT

April 1989 - March 1990

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FOREWORD

It is my privilege to submit the Annual Report for the year 1989-90 of the Institute of Mathematical Sciences.

The Institute, as has been observed in the previous annual reports is in the process of making a transition from its moderate size in the sixties and seventies to an Institute of National Importance with increased scope and size to be achieved in the nineties. It is gratifying to note the commitment of Department of Atomic Energy, Government of India, and the continued interest of the Tamil Nadu Government. The year, under review, saw to it that the necessary support facilities - a new Library building, Hostel and Guest House buildings - were built thanks to the generous grants made available by the Department of Atomic Energy. We hope to augment our library so that it could serve as an all-inclusive comprehensive reference library in various subdisciplines of Mathematical Sciences. With increased guest house facilities, we should be able to welcome a number of scholars to visit the Institute and interact with us in various research activities.

The Institute is proud to have in its faculty a number of highly competent active research workers, the activities of whom are detailed in the report. It is but natural that they are regarded as front runners in the national stream and are invited to participate and give lectures in both national and international gatherings.

During the year under review Prof. K.R. Unni officiated as the Director-in-charge and coordinated with the Registrar, Dr. V. Varaprasada Rao, the various building activities and the general administration of the Institute. To them I owe my gratitude. I am thankful to Prof. N.D. Hari Dass, Dr. R. Jagannathan, Dr. Krishna Maddaly and Mr. T.V. Vasudevan, for their valuable help in the preparation of this report.

September 1990

R. Ramachandran
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* *Prof. R. RAMACHANDRAN, is ex-officio, member of the Board of Governors and the Finance Committee from 18th June 1990 upon assumption of office as the Director of the Institute of Mathematical Sciences, Madras.*

Dr. V. VARAPRASADA RAO, Ph.D., I.A.S., Registrar, The Institute of Mathematical Sciences, Madras, is ex-officio, the Secretary to the Board of Governors and the Finance Committee.

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* *Whose tenure at the Institute was over in 1989-90*

+ *On leave from the Institute*

** *Director-in-charge until 18th June 1990*

STUDENTS

Junior Research Fellows

Mr. J.Anthony ANAND*	(Mathematics)
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Ms. M. GEETHA	Mr. M.G. RADHAKRISHNAN
Ms. M. USHA NANDHINI	Mr. M. VARADARAJ
Mr. G. ASHFACK AHMED	Mr. M. MUTHUKRISHNAN
Mr. V. JAYARAMAN	Mr. D. AMULRAJ
Mr. T.R. NARAYANAN	Mr. N. RAJASEKARAN
Mr. G. ELUMALAI	Mr. M. TAMIL MANI
Mr. M. KANNIAPPAN	Mr. A. RAVINDRAN
Mr. M. MUNUSWAMY	Mr. N. RAVICHANDRAN

* *Whose tenure at the Institute was over in 1989-90*

RESEARCH WORK : SOME OUTLINES

PHYSICS

The research activities in Physics spanned a vast area including such diverse topics as condensed matter physics, non linear dynamics, stochastic processes, quantum optics, electron beam optics, generalisations in the quantum theory of angular momentum, classification of interactions based on special relativity, supersymmetric quantum mechanics, Fermi-Bose equivalence in field theory, properties of S-matrix poles, quantisation of non-linear sigma models, compactification schemes for higher dimensional theories, quantum-chromodynamics, string theories, high energy physics phenomenology, two-dimensional quantum gravity, perturbative quantum gravity, neutrino astrophysics, cosmology, and neural network theory. A brief description of the salient features of these works is given below :

CONDENSED MATTER PHYSICS

The microscopic pseudo-spin model of superfluid ^4He was shown to be equivalent to a Gross-Pitaevskii matter field interacting with a gauge field identified with that part of the superfluid velocity possessing a non-vanishing curl. The non-linear evolution equation for the order parameter in such models was shown to have pulse-type solitary wave solutions.

Various aspects of the RVB-theory of high- T_c superconductivity were investigated. Specifically, the chiral symmetry breaking as well as the non-fermi liquid aspects of these theories were elucidated. In addition, the SU (2) solutions in RVB theory, tunnelling between RVB-conductors and normal metals, RVB instabilities in ordered antiferromagnets are also being studied. Work is also in progress to construct fermionic mean field theories with broken chiral symmetry expected to be relevant for the study of doped Mott-insulators and frustrated antiferromagnetic systems. The low energy spin fluctuations present in the so-called t-J model are being studied to explain the non-occurrence of the Koringa behaviour in Cu nuclei in high- T_c materials.

Other topics studied were a phenomenological model for high- T_c superconductivity based on structural transformations, as well as anyonic superconductivity. A generalisation of Davydov's model that is valid for non-adiabatic situations has also been derived.

OPTICS

Hamilton's turns were used to show that all SU (2) polarisation optical systems can be synthesised with two quarter-wave plates and one half-wave plate. Thermofield methods were used to find thermal counter-parts of non-classical states in quantum optics. Other investigations in quantum optics included : coherent and squeezed states associated with generalised commutation relations, relationship between non-depolarising systems and the degree of polarisation, change in spectral and coherence properties under reflection and transmission, optical interference and Hannay angle, twisting quadratic phase and configuration space density operators.

The development of the quantum theory of electron beam optics, based entirely on the Dirac equation, has been initiated.

FIELD THEORY

Quantum effects in the non-linear sigma model compactification for $M^4 \times S$ and the stability of the classical solutions were studied. This has also been used as a model for the early universe.

The $O(3)$ non-linear sigma model in $2+1$ dimensions was analysed to elucidate the inequivalent quantisations of systems with topologically non-trivial classical phase spaces. For sigma models on an arbitrary genus Riemann surface the fundamental groups of the configuration space and their finite dimensional unitary representations were studied.

The equivalence of a free Dirac fermion and a complex scalar field coupled to abelian Chern-Simons theory in $2+1$ dimensions was explicitly established using path-integral techniques. Fermion fields were explicitly constructed.

The Hilbert space of $N=2$ supersymmetric Wess-Zumino models have been shown to be noninvariant under the reflection symmetry of the Hamiltonian. They are in fact shown to be at least eight-fold degenerate.

A systematic expansion of the regulated Witten index for SUSY quantum mechanics in one and two dimensions was developed which has the virtue of yielding the entire index as the first term.

QUANTUM GRAVITY AND STRINGS

A generalised Gauss-map has been used for a new formulation of string theories with extrinsic curvature. String theories with constraints have been shown to be equivalent to constrained CP models.

Two dimensional quantum gravity theories were formulated in the Hamiltonian formalism. Ambiguities were found leading to inequivalent but acceptable quantisation schemes. The Hilbert space for pure gravity case was explicitly constructed.

The observables in perturbative quantum gravity are found not to be gauge-independent. Scale-independence of all physical theories has been exploited to interpret this result so as to yield a consistent formulation of the theory.

PARTICLE PHYSICS

A chromoelectric vacuum has been constructed which shows confinement for some colour degrees of freedom. Attempts are being made to include fermions in the picture.

A new approach to non-abelian gauge theories based on duality - transformations has been constructed. Its implications for the confinement mechanism are being studied.

A variational approach to lattice gauge theories is being developed for $SU(3)$ gauge theories as well as for theories with fermions.

The QCD sum rule technique was used to get a satisfactory explanation of the recent

EMC results on the proton spin-structure functions. The role of the axial anomaly in the determination of the hadronic matrix elements was clearly stressed. A new sum rule relating various spin-structure functions has been derived which isolates an universal mass scale agreeing with the constituent quark mass.

Mass shifts for the weak bosons due to the breaking of colour symmetry in the integrally charged quark model was calculated. Dynamical interconnections between electromagnetic and weak phenomena were studied. The stability of resonance poles was proved.

TOPICS IN OTHER AREAS

An action function was formulated based on the dynamics of neural networks described by Caianiello-type equations. An alternative method for memory organisation was given.

The time evolution of a space curve was shown to be associated with geometric phases under some circumstances. The results were applied to antiferromagnetic chains.

The "principle of equivalence of all observers with same paths" combined with a geometry based on area replacing one-parameter time has been shown to yield a classification of interactions in terms of conformal classes of Riemann surfaces.

A singularity free universe viewed as a black-hole interior, has been characterised geometrically in terms of a space with negative curvature. Such an universe has been found to have a high entropy content.

A new mechanism for causing helicity-flip for massive neutrinos based on gravitational interactions was considered. It was used to constrain some important parameters.

Redheifer-type differential equations were obtained in some cases by imbedding techniques. This analysis has potential interest in reactor theory.

A detailed investigation of the q -generalisation of the quantum theory of angular momentum was undertaken. Various properties of q -3- j and q -6- j coefficients as well as the q -generalisation of the reversal of ${}_{p+1}F_p(z)$ series were established.

Nonlinear dynamics of a uniaxially ferromagnetic chain was studied in detail.

Stochastic processes subjected to Feller's natural boundary conditions were reformulated as initial value problems. Non-Markov behaviour was studied in the specific context of quantum Langevin equations and quadratic systems. The interaction between quadratic systems and heatbaths were studied in fully coupled situations as well as in the rotating wave approximation. Fluctuation-dissipation relations and KMS conditions in such systems were studied.

MATHEMATICS

In mathematics the current research at the Institute is broadly in the fields of Functional analysis, Algebra, and Number theory.

Work has been done on real function algebras on compact Hausdorff spaces and conditions under which these become maximal in some sense are being formulated. There has been some progress on the construction of hypergroups, their relationship with inverse spectral transform and further connections with completely integrable systems. For a class of partial differential operators asymptotic completeness has been proved. In the study of disordered systems, existence of extended states has been proved for a certain class. In number theory a result on splitting of primitive primes associated with arithmetic progressions over number fields having tamely ramified primes has been proved.

A result on the number of ways of expressing n as a sum of four squares has been proved. A known zero result, in the case of summatory function of the characteristic function of square-free numbers, has been improved. A good estimate has been obtained on the number of elliptic pseudoprimes unconditionally and also it has been shown that almost all L-functions are different from zero at $s = 1/2$. A result on analytic functions, that the value of an analytic function at the centre is smaller than the mean over any diameter, has also been shown.

THEORETICAL COMPUTER SCIENCE

The theoretical computer scientists in the Institute study mainly distributed systems. Axiomatization of various classes of distributed systems has been carried out and relationships between these classes have been exploited to transfer results between them. The main emphasis of this work has been to consider partial order models of concurrency and to contrast them with interleaving models. A hierarchy of systems of communicating sequential agents has been defined and completely axiomatized in tense logics. These logics are used to reason about distributed protocols.

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Mod. Phys. Lett. A5 (1990) 593
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G. RAJASEKARAN

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R. SIMON

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R. SRIDHAR

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system
Proc. Conf. on Transport Theory, May 1989, Blackburg, Virginia Polytechnique

PAPERS SUBMITTED FOR PUBLICATION / PREPRINTS ISSUED

Radha BALAKRISHNAN (with A.R. BISHOP and R. DANDOLOFF)

Geometric phase in the classical continuous antiferromagnetic Heisenberg chain, Preprint
LA-UR-90-260, Los Alamos National Lab., U.S.A. (submitted for publication)

Radha BALAKRISHNAN

Solitary-wave propagation in superfluid ^4He films, Preprint IMSc/90/4 (submitted for
publication)

Radha BALAKRISHNAN, R. SRIDHAR and R. VASUDEVAN

Vortices in the Pseudospin model of Liquid ^4He and gauge theories (submitted for publica-
tion)

G. BASKARAN

Comment on n-pairing and ODLRO in Hubbard model (submitted for publication)

- R. JAGANNATHAN
Quantum theory of electron lenses based on the Dirac equation, Preprint IMSc/90/3 (submitted for publication)
- R. PARTHASARATHY (with K.S. VISWANATHAN)
Generalized Gauss map in R^n (submitted for publication)
- V. RADHAKRISHNAN (with W.C. SCHIEVE)
The Ornstein-Uhlenbeck process with Feller's natural boundary conditions (submitted for publication)
- V. RADHAKRISHNAN (with D.K. CAMPBELL)
Non-adiabatic non-linear equation for the Davydov model (submitted for publication)
- R. SIMON (with G.S. AGARWAL)
Berry phase, interference of light beams and Hannay angle (submitted for publication)
- R. SIMON (with S. CHATURVEDI, A.K. KAPOOR, R. SANDHYA and V. SRINIVASAN)
Generalized commutation relations, their coherent and squeezed states (submitted for publication)
- R. SIMON (with W. WANG and E. WOLF)
Changes in the coherent and spectral properties of light reflected from a dielectric slab (submitted for publication)
- R. SIMON (with N. MUKUNDA)
Twisted Gaussian Schell-model beams (submitted for publication)
- K. SRINIVASA RAO and V. RAJESWARI
On the reversal of the general basic hypergeometric series (submitted for publication)
- K. SRINIVASA RAO, T.S. SANTHANAM and V. RAJESWARI
Multiplicative Diophantine equations (submitted for publication)
- R. VASUDEVAN (with R. CHAKRABARTI)
Quadratic systems and heatbaths (submitted for publication)

PUBLICATIONS EDITED

- G. BASKARAN (with A.E. RUCKENSTEIN, E. TOSATTI and Yu. LU)
"Strongly Correlated Electron Systems"
World Scientific, Singapore, 1989

SCIENTIFIC ARTICLES IN POPULAR MAGAZINES and OTHER PUBLICATIONS

- K. SRINIVASA RAO
Review of three books on Sir C.V. Raman, Patriotic and People-oriented Science and Technology (PPST) Foundation Bulletin No.17 (dated 1988)

K. SRINIVASA RAO
Sanskrit and Artificial Intelligence
in Proc. Diamond Jubilee celebrations of the Sanskrit College, Madras (1989)

K. SRINIVASA RAO
Computers in Education
Phys. Education (1990) - to appear

MATHEMATICS

S. ARUNDHATHI
A note on the peak points for real function algebras
Indian J. Pure and Appl. Math. 21 (1990) 155

R. BALASUBRAMANIAN and S.D. ADHIKARI (with A. SANKARANARAYANAN)
An Ω -result related to $r_4(n)$
Hardy-Ramanujan Journal 12(1989) 20

R. BALASUBRAMANIAN (with K. RAMACHANDRA)
On the frequency of Titchmarsh's phenomenon for $\zeta(s)$ -VI
Acta Arithmetica LIII (1989)

R. BALASUBRAMANIAN (with K. RAMACHANDRA)
Some local convexity theorem for zeta-function-like analytic function
Hardy-Ramanujan Journal 11 (dated 1988)

R. BALASUBRAMANIAN (with K. RAMACHANDRA)
A lemma in complex function theory - I and II
Hardy-Ramanujan Journal 12(1989) 1; 12 (1989) 6

R. BALASUBRAMANIAN (with K. RAMACHANDRA)
On square-free numbers
Proc. Ramanujan Centenary Conference, (Ramanujan Math. Soc. Pub. dated 1988) p.27

R. BALASUBRAMANIAN (with K. RAMACHANDRA)
Titchmarsh's phenomenon for $\zeta(s)$
Proc. Colloq. Number Theory and Related Topics, (TIFR Pub. Bombay, dated 1988) p.13

K.R. UNNI
Translation invariant operators
Proc. Symposium on "Operator Theory and Functional Analysis", conducted by the Centre for Mathematical Sciences (Trivandrum) at Cochin University, July 1989

S. VENKATARAMAN (with M. BHASKARAN)
On splitting of primes in an arithmetic progression - I
to appear in Acta Arithmetica

S. ARUNDHATHI

An analogue of Glicksberg's theorem for real function algebras
(submitted for publication)

S. ARUNDHATHI

An analogue of Bade and Curtis theorem for real function algebras
(submitted for publication)

R. BALASUBRAMANIAN (with K. RAMACHANDRA)

An alternative approach to a theorem of Tom Meurman
(submitted for publication)

R. BALASUBRAMANIAN (with M. RAM MURTY)

Elliptic pseudoprimes
(submitted for publication)

R. BALASUBRAMANIAN (with V. KUMAR MURTY)

On the nonvanishing of Dirichlet L-function at $s=1/2$
(submitted for publication)

Krishna MADDALY

Anderson model with decaying randomness - Existence of extended states
(submitted for publication)

K.R. UNNI

Mathematical Research in India

Calcutta Math. Soc. News Bulletin 12(1989) 10

THEORETICAL COMPUTER SCIENCE

Kamal LODAYA (with R.K. SHYAMSUNDAR)

Proof Theory for exception handling in a tasking environment
to appear in Acta Informatica

R. RAMANUJAM, Kamal LODAYA and P.S. THIAGARAJAN

Temporal logics for communicating sequential agents : Part I
(Preprint IMSc/89/15) (submitted for publication)

PARTICIPATION IN CONFERENCES AND OTHER PROFESSIONAL ACTIVITIES OF THE ACADEMIC STAFF

Visits to other Institutions in India and abroad

Radha BALAKRISHNAN	Center for nonlinear Studies, Los Alamos National Lab., USA (24 Aug. - 20 Nov. '89)
R. BALASUBRAMANIAN	Institut Henri Poincare, France (June - July'89); Univer- sity of Bordeaux, France (July - Aug'89) - Under Indo- French cultural exchange programme
G. BASKARAN	Institute for Theoretical Physics, University of Califor- nia, Santa Barbara, USA (1 April - 30 June '89) Princeton University and IBM Research Lab. Yorktown Heights, NY, USA (Sep. - Oct. '89)
Rahul BASU	International Centre for Theoretical Physics (ICTP), Trieste, Italy (26 June - 20 Aug. '89) - Under the Federation Scheme Institut de Etude Scientifiques de Cargese, Cargese, Corsica (17 July - 3 Aug. '89) Institute of Physics, Bhubaneswar (5-7 Feb. '90) Indian Institute of Technology (IIT), Kanpur (9-12 Feb. '90)
Hemant BHATE	Department of Physics, Bharatidasan University, Tiruchi (29 Nov. - 6 Dec. '89 and Feb. '90) Indian Statistical Institute, Bangalore (March - April '90)
N.D. HARI DASS	University of California, Santa Barbara, USA (Aug. '89) Institute of Theoretical Physics, University of Utrecht, Utrecht, Netherlands (Sept. - Oct. '89)
Kamal LODAYA	Tata Institute of Fundamental Research (TIFR), Bombay (Dec. '89 - Jan'90)

Krishna MADDALY	University of Sambalpur (6 - 19 Aug.'89) Indian Statistical Institute, Bangalore (5 - 22 Feb.'90)
K.H. MARIWALLA	TIFR, Bombay (Aug.'89)
G. RAJASEKARAN	TIFR, Bombay (April - Nov.'89) Physical Research Laboratory, Ahmedabad (18-21 Sept.'89)
V. RAJESWARI	ICTP, Trieste, Italy (1-30 Sept.'89) - Under the Federation Scheme Department of Physics, University of Gulbarga, Gulbarga (5-14 Feb.'90)
R.RAMANUJAM	TIFR, Bombay (1-7 Jan.'90)
R. SIMON	Polytechnic University, Brooklyn, New York, USA (20-25 June '89) University of Rochester, USA (26 June - 8 July '89) GHS-Universitat, Essen, FRG (9-14 July'89) Centre for Theoretical Studies (CTS), Indian Institute of Science (IISc), Bangalore (29 Jan. - 4 Feb. '90)
R. SRIDHAR	Department of Physics, University of Jordan, Amman, Jordan (3-17 Sep.'89)
K. SRINIVASA RAO	Gulbarga University, Gulbarga (30 Oct. - 9 Nov.'89)
R. VASUDEVAN	Physics Department, Central University of Hyderabad, Hyderabad (Dec. '89; March'90)

Participation in Conferences

Radha BALAKRISHNAN	Workshop on "Open problems in Classical Condensed Matter Physics", Department of Physics, IISc, Bangalore, 17 - 21 April '89
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"A Modern Course on Quantum Mechanics", IIT, Madras, May '89 (Lecture on "Spin coherent state representation")

One-day symposium on "Topics in Condensed Matter Physics", IMSc, Madras, 26 Feb. '90 (Seminar on "Nonlinear dynamics in superfluid 'He'")

R. BALASUBRAMANIAN

Conference on L-functions, Durham, UK, July '89

Journées Arithmétique, Luminy, France, July '89 (Talk on "Erdős-Woods conjecture")

G. BASKARAN

Conference on High- T_c Super-conductors, Institute of Theoretical Physics, Santa Barbara, June '89 (Talk on "Chiral symmetry breaking in high- T_c superconductors")

Workshop on "Strongly Correlated Electron Systems", ICTP, Trieste, Italy, 1-30 July '89 (One of the Directors of the Workshop)

Adriatico Research Conference on "Mechanisms of High- T_c Superconductors", ICTP, Trieste, Italy, 24-27 March '90 (Invited talk on "High- T_c theory")

International Colloquium on "Quantum Field Theory", TIFR, Bombay, Jan '90 (Invited talk)

International Conference on "Superconductors", Bangalore, 10-14 Jan '90 (Invited talk)

"Landau-IISc meeting", IISc, Bangalore, 15 Feb '90 (Invited talk)

"Nordita-Landau Institute Meeting", Moscow, Oct '89 (Invited talk)

International Conference on "Highly Correlated Systems" Santa Fe, New Mexico, USA, 16-19 Sep. '89 (Discussion on the Studies of High- T_c theory as one of three panel members)

Workshop on High- T_c superconductors, Saha Institute of Nuclear Physics, Calcutta, 27 Dec. - 2 Jan. '90 (Five talks)

Rahul BASU

"Summer School in High Energy Physics and Cosmology", ICTP, Trieste, Italy, June - Aug. '89

"Summer School in Particle Physics", Institute de Etude

- Scientifiques de Cargese, Cargese, 17 July - 3 Aug.'89
(Talk on "Gluon confinement in chromoelectric vacua")
- G. DATE "International Colloquium on Modern Quantum Field Theory", TIFR, Bombay, 7-14 Jan.'90. (Talk on "Inequivalent quantizations for non-linear σ -model")
- N.D. HARI DASS "International Symposium on Lepton-Photon Interactions", Stanford, USA, 8-15 Aug.'89
"International Colloquium on Modern Quantum Field Theory", TIFR, Bombay, 5-9 Jan.'90 (Talk on "Hamiltonian formulation of 2-d quantum gravity")
Workshop on "Recent developments in Quantum Field Theory", CTS, Bangalore, March'90 (Talk on "Gauge invariance in perturbative quantum gravity")
- Kamal LODAYA Workshop on "Logics and Models of Concurrency", TIFR Centre, Bangalore, 26-30 June'89 (Talk on "Systems of communicating sequential agents")
"Indo-French Seminar on Theoretical Computer Science", Goa, 11-15 Dec.'89
9th Conference on "Foundations of Software Technology and Theoretical Computer Science", Bangalore, Dec.'89
- Krishna MADDALY Conference on "Harmonic Analysis", IIT, Kanpur, 27-29 Jan.'90 (Talk on "Spectral properties of disordered systems")
- K.H. MARIWALLA "International Symposium on Supernovae and High Energy Astrophysics", Variable Energy Cyclotron Centre, Calcutta, 27-29 Dec.'89
(Talks on 1) "Strings without strings", 2) "Singularity free universe, black holes and spaces of negative curvature of finite volume"; Chaired two sessions)
- M.V.N. MURTHY SERC School on "Theoretical High Energy Physics", IIT, Kanpur, 4 Dec. '89 (A course of 10 Lectures on "Standard Model")
UGC Summer School for College Teachers, University of Mysore, 5-13 May'90 (A course of 8 lectures on

"Quarks and Partons")

G. RAJASEKARAN

"Seminar on Scientific Values and Excellence in Science", Indian National Science Academy, Delhi, 18 Apr.'89

"Symposium on Current Trends in Physics", Institute of Physics, Bhubaneswar, 1-3 Sept.'89 (Invited talk on "Shadow Poles and Hadronic Molecules")

Topical Meeting on "CP Violation", SN Bose National Centre for Basic Sciences, Calcutta, 3-5 Jan.'90 (Concluding summary talk)

"International Colloquium on Modern Quantum Field Theory", TIFR, Bombay, 8-13 Jan.'90

"QCD Workshop", IMSc, Madras, 1-2 March'90 (Talk on QCD with broken colour)

V. RAJESWARI

Seventh Young Physicists Colloquium of the Indian Physical Society, Saha Institute of Nuclear Physics, Calcutta, 23-24 Aug.'89 (Talk on "Topics in quantum theory of angular momentum")

Conference on "Computations in Physics and Physics in Computations", ICTP, Trieste, Italy, 4-9 Sep.'89

"National Seminar on Group Theoretic Techniques", Department of Engineering Mathematics, Andhra University, Waltair, 28 Feb.- 2 March '90 (Talk on "Group theory of generalized hypergeometric functions")

R. RAMANUJAM

Workshop on "Logics and Models of Concurrency", TIFR Centre, Bangalore, 26-30 June'89 (Talk on "Distributed transition systems")

"Indo-French Seminar on Theoretical Computer Science", Goa, 11-15 Dec.'89 (Talk on "Indian contributions to the theory of Logic Programming"; Coordinator for Logic Programming)

R. SIMON

"A modern course in Quantum Mechanics", IIT, Madras, 10-31 May '89 (Three Lectures on "Generalized coherent states")

"Coherence and Quantum Optics-VI", University of Rochester, USA, 26-28 June'89 (Presented papers on "Geometric phases in optics: Some pedestrian considerations" and "Geometric representation for squeez-

ing : The abcd-laws")

Workshop on "Symmetries and Singularity Structure Aspects of Nonlinear Dynamical Systems", Bharathidasan University, Tiruchi, 29 Nov.- 2 Dec.'89 (Invited talk on "Symmetry groups and geometric phases"; Chaired a session)

Second IAP/DST symposium on "Lasers and Applications", Banaras Hindu University, Varanasi, 11-15 Dec.'89 (Invited talk on "Geometric phase in optics : Is it classical or quantum?")

R. SRIDHAR

"V Petra School of Physics", Amman, Yarmdik, Jordan, 3-10 Sep.'89 (Talks on "A pseudospin treatment of superfluid hydrodynamics of liquid ^4He " and "Structural phase transitions and high- T_c superconductivity")

UGC Seminar on "Recent Trends in Mathematics", CBM College, Coimbatore, 7-9 Feb.'90 (Talk on "Non-linear equations in theoretical physics")

K. SRINIVASA RAO

UGC Refresher Course in Physics : Nuclear, Atomic and Molecular Physics", Bharatidasan University, 12-14 June'89 (4 Lectures on "Nuclear Models")

"National Seminar on Emerging Trends in Higher Education : Teacher's role and responsibilities", Andhra University, Waltair, July'89 (Invited talks on "Artificial intelligence" and "Computers in education")

Symposium on "Special Functions", 77th Indian Science Congress, Cochin, Feb'90 (Invited talk on "Generalized hypergeometric functions and quantum theory of angular momentum")

"National Seminar on Group Theoretic Techniques", Andhra University, Waltair, March'90 (Invited talk on "Clebsch-Gordan and Racah Coefficients in the algebra of $SU_q(2)$ ")

"National Symposium on Recent Trends in Nuclear Physics and Solid State Physics", University of Madras, March '90 (Invited talk on "Quantum theory of angular momentum - a new generalization")

K.R. UNNI

"Refresher Course in Mathematics : Topology", University of Madras, 17 July - 14 Aug.'89 (Invited participant as Resource Person)

"National Symposium on Operator Theory and Functional Analysis" conducted by the Centre for Mathematical Sciences, Trivandrum, at Cochin University, Cochin, 28-30 July '89 (Invited talk on "Translation invariant operators")

"Seminar on Mathematics Education and Research in India", Calcutta Mathematical Society, Calcutta, 9-10 Sept.'89 (Invited talk on "Mathematical Research in India")

R. VASUDEVAN

"National Symposium on Recent Trends in Nuclear and Solid state Physics", Department of Physics, Madras University, 19-20 March '90 (Member of the Organising Committee)

Seminars / Lectures given outside the Institute

Radha BALAKRISHNAN

"Nonlinear dynamics in superfluid ^4He ", Center for Nonlinear Studies, Los Alamos National Lab, USA (Nov. '89)

G. BASKARAN

Seminars at Nordita, Denmark (Oct. '90) and IISc, Bangalore (1989)

Rahul BASU

"Confinement and the QCD vacuum" and "Statistical mechanics of anyons", Institute of Physics, Bhubaneswar (Feb. '90) - Under TPSC programme

"Confinement and the QCD vacuum" and "Statistical mechanics of anyons", IIT Kanpur (Feb. '90) - Under TPSC programme

Hemant BHATE

"The inverse scattering transform", Five lectures, Department of Physics, Bharatidasan University, Tiruchi (Feb. '90)

"Inverse spectral problems" and "Periodic solutions to integrable nonlinear evolution equations", Four lectures, Indian Statistical Institute (ISI), Bangalore (March-April '90)

- G.DATE "Inequivalent quantizations for nonlinear σ -model", Department of Theoretical Physics, Madras University, Madras (15 Feb. '90)
- N.D. HARI DASS "Two dimensional quantum gravity", Institute of Theoretical Physics, Santa Barbara, USA (Aug. '89)
 "Hamiltonian formulation of two dimensional quantum gravity" Niels Bohr Institute, Copenhagen, Denmark (Sep. '89)
 "Two dimensional quantum gravity", Institute of Theoretical Physics, University of Utrecht, Netherlands (Oct. '89)
 "Hamiltonian formulation of 2-d quantum gravity", National Institute of High Energy Physics, Amsterdam, Netherlands (Oct. '89)
 "Hamiltonian formulation of 2-d quantum gravity", Max Planck Institute for Physics, Munich, West Germany (Oct. '89)
- Krishna MADDALY "Random schrodinger operators", Department of Theoretical Physics, Madras University, Madras (Sept. '90)
 "Random schrodinger operators", TIFR Centre, Bangalore (21 Feb. '90)
- K.H. MARIWALLA "Strings without strings", TIFR, Bombay (Aug. '89)
- M.V.N. MURTHY "Spin structure of the proton", Department of Theoretical Physics, University of Madras, Madras (13 March '90)
- PI. MUTHURAMALINGAM "An introduction to spectral and scattering theory", ISI, Bangalore (Feb. '90)
- G. RAJASEKARAN "W and Z boson masses in ICQ model", TIFR, Bombay (29 June '89)
 "Molecular hadrons and shadow poles", TIFR, Bombay (29 Sep. '89)
- V. RAJESWARI "Multiplicative Diophantine equations and polynomial zeros of the angular momentum coefficients", ICTP, Trieste, Italy (20 Sep. '89)
 20 lectures on "Reactor Physics", Department of Phys-

ics, University of Gulbarga, Gulbarga (5 - 14 Feb. '90)

"Topics in quantum theory of angular momentum",
University of Gulbarga, Gulbarga (14 Feb. '90)

R. SIMON

"Geometric phases - Some elementary experiments",
Polytechnic University, Brooklyn, New York, USA
(23 June '89)

"Geometric phases in optics : A unified approach",
Universitat-GHS Essen, FRG (12 July '89)

R. SRIDHAR

"Superfluidity", "Superconductivity", Department of
Physics, University of Jordan, Amman (Sep. '89)

K. SRINIVASA RAO

"Srinivasa Ramanujam : His life and work", Depart-
ment of Mathematics, Gulbarga University (6 Nov. '89)

"The standard model", Department of Physics, Gul-
barga University (7 Nov. '89)

"Artificial Intelligence", Gulbarga University (8 Nov.
'89)

"Quantum theory of angular momentum", Department
of Nuclear Physics, Andhra University, Waltair (28 July
'89)

"Nuclear models and nuclear reactions", Department
of Physics, Gulbarga University (30 Oct. - 9 Nov. '89)

Inauguration of Physics Association of Madras Christian
College, "The standard model" and "AI and the current
computer scene" (27 Sep. '89)

"Computers and Programming", Computer Science
Department, University of Madras (March '90)

K.R. UNNI

"Usefulness of Hahn-Banach theorem", 3 Colloquium
lectures, Department of Mathematics, Anna University
(19,23 and 26 Oct. '89)

Other Professional activities

R. BALASUBRAMANIAN is the Co-Editor of the Hardy-Ramanujan Journal and a member of the Editorial Board of the Indian Journal of Pure and Applied Mathematics. He is

a member of Sectional Committees of the Council of Scientific and Industrial Research (CSIR), Indian National Science Academy (INSA) and the Indian Academy of Sciences (IASc). He is also a member of the Post-Graduate Board of Studies of the Pondicherry University.

G. BASKARAN and V. BALAKRISHNAN (I.I.T. Madras) organised a two day meeting on "Highlights in Condensed Matter Physics" in which about twelve Soviet scientists (including the leading condensed matter theorists Lorkin, Pokrovsky and Finkelstein) participated and gave talks. The main focus of the meeting was on high- T_c superconductors and many phenomenological aspects as well as microscopic RVB-theory were discussed.

G. BASKARAN has been awarded the Staff Associateship of the International Centre for Theoretical Physics (ICTP) Trieste, Italy starting Jan.'90.

N.D. HARI DASS organized a 2-day meeting on "Quantum Chromodynamics" (1-2 March'90) to inaugurate the installation of the HP-9000 Computer System under the Department of Science and Technology (DST) project. About 15 speakers covered various aspects of QCD.

G. RAJASEKARAN is a member of the Governing Councils of a number of National Institutions, and many other national-level committees. He has also participated in the UGC-sponsored educational TV programme on "CP-violation" produced by Prof. Partha Ghose of the S.N. Bose National Centre for Basic Sciences, Calcutta.

K. SRINIVASA RAO gave a talk, in the All India Radio (Madras) broadcast (12 March '90) on "Sanskrit and Artificial Intelligence : A New Perspective".

K.R. UNNI is a member of the Board of Editors of the Bulletin of Calcutta Mathematical Society. He is also a member of the Governing Council of the S.N. Bose School of the Calcutta Mathematical Society.

R. VASUDEVAN is a member of the Board of Studies of the Elite School of Optometry, Madras (A unit of the Medical Research Foundation, Madras). He is also an Associate Editor of the International Journals, Applied Mathematics and Computation (North-Holland Pub., Netherlands) and Neurological Research (Butterworth-Heinemann Pub., U.K.)

OTHER NEWS

Awards and Honours

R. RAMANUJAM has been awarded the Geetha Udgaonkar Award for the best Ph.D. Thesis in 1988-89 (Bombay University)

Ph.D. Awarded

V. RAJESWARI received her Ph.D. Degree from the University of Madras (Title of the Thesis : "Topics in Quantum Theory of Angular Momentum"; Thesis Supervisor : K. SRINIVASA RAO)

Ph.D. Course Work

During 1989-90 the programme of the two-semester course work for the first year Ph.D. students in Physics was as follows :

I SEMESTER(Oct. '89 - Feb. '90)

Subject	Lecturers
Mathematical Methods	R. JAGANNATHAN R. SIMON K. SRINIVASA RAO R. VASUDEVAN
Classical Mechanics	K.H. MARIWALLA R. SRIDHAR
Quantum Mechanics	G. DATE K. SRINIVASA RAO
Statistical Mechanics and Condensed Matter Physics	V. RADHAKRISHNAN H.S. SHARATCHANDRA

II SEMESTER (March - July '90)

Classical Fields	K.H. MARIWALLA
Quantum Fields	N.D. HARI DASS
Statistical Mechanics and Condensed Matter Physics	Ramesh ANISHETTY Radha BALAKRISHNAN R. SRIDHAR
Particle Physics	M.V.N. MURTHY G. RAJASEKARAN

DST - Project

The Department of Science and Technology (DST) sponsored project on "Lattice Gauge Theories" (Principal Investigator : N.D. HARI DASS) has been initiated with the installation of a HP-9000 computer system. Programs have been developed to generate various aspects of SU(3) gauge theory to high numerical precision needed for the project.

Theoretical Physics Seminar Circuit (TPSC) Programme

The Institute continued its participation in the TPSC programme sponsored by the Department of Science and Technology to promote close collaboration among the theoretical physicists working at different research centres. During 1989-90 the Institute had eight visitors under this programme : Biswajyoti DEY (Plasma Research Institute, Gandhinagar), Diptiman SEN (Centre for Theoretical Studies, Indian Institute of Science, Bangalore), R.E. AMRITKAR (Poona University, Poona), Avinash DHAR (Tata Institute of Fundamental Research, Bombay), S. DATTA GUPTA (Jawaharlal Nehru University, Delhi), Ashoke SEN (Tata Institute of Fundamental Research, Bombay), C.S. AULAKH (Institute of Physics, Bhubaneswar), A.P. BALACHANDRAN (Syracuse University, U.S.A). This year the TPSC activities of the Madras Centre were extended to include Bharatidasan University, Tiruchi and Cochin University for Science and Technology, Cochin as associate centres.

Library

During 1989-90, 892 volumes have been added to the collection of the library and about 211 national and international scientific journals are currently being subscribed to. Now, the library has a collection of more than 25000 volumes (books and bound periodicals). As in previous years the library is receiving many journals and lecture notes on exchange basis from well established scientific societies and institutions, and on the average about 300 preprints are received every month from scientific institutions in India and abroad. Besides, the members of the Institute, about 1500 outsiders have made use of the library during the past year.

The new library building was opened in February '90 and with the shifting of the library to this more spacious building we hope to offer better facilities and service to the users of our library.

We are thankful to the following for donation of many useful books to the library during 1989-90. Mr. G.H. GADIYAR, I.M.Sc., Mr. Madhavan MUKUND, I.M.Sc., Dr. R. RAMANUJAM, I. M.Sc., Prof. A. SUBRAMANIAN, High Energy Physics Group, T.I.F.R. Bombay, Department of Physics, Indian Institute of Science, Bangalore, U.S. Library of Congress Office, New Delhi, Tohoku University, Japan, The Research Centre for Advanced Mathematics, Nagoya University, Japan.

VISITORS

S. STEPANOV, Steklov Institute and Moscow University, Moscow, USSR (4 - 8 April '89)
(Coding theory and arithmetic)*

C. ADIMOOLAM, Bharathidasan University, Tiruchi (13 April '89)
(Quantum Groups)

C. PREMKUMAR YESUDIAN, Scott Christian College, Nagercoil (4 - 12 May '89)

T. PRADHAN, Utkal University, Bhubaneswar (10 May '89)
(Para-Fermi-Bose or Bhabha symmetry)

B.V. BABY, Bharata Mata College, Cochin (15 - 27 May '89)

K.P. SINHA, Indian Institute of Science, Bangalore (22 May '89)
(Charged bosons and high- T_c superconductivity)

A.O. BARUT, Boulder, Colorado, USA (24 May '89)
(The theory of electrons or what is an electron?)

M.S. RAGHUNATHAN, Tata Institute of Fundamental Research, Bombay (22 June '89)
(Algebraic groups and simple groups)

K.K. MUKHERJEE, Indian Statistical Institute, New Delhi (29 June '89)
(Lefschetz theory for manifolds with boundary)

A. SINHA, North Eastern Reg. Inst. of Science and Technology, Itanagar, Nirjuli, Arunachal Pradesh (1 - 18 July '89)

J. JAYARAMAN, University of Illinois at Chicago, USA (6 July '89)
(Hydrogen and Lithium as a constrained (super) Wigner oscillator in four dimensions)

REMY Y. DENIS, Department of Mathematics, Gorakhpur University, Gorakhpur (18-24 July '89)

K. RAVISHANKAR, Department of Mathematics and Computer Sciences, SUNY at New Paltz, USA (28 July '89)
(Power law scaling of top; Lyapunov exponent of a product of random matrices)

PRABHAKAR RAGHAVAN, IBM Thomas Watson Research Centre, Yorktown Heights, USA (3 Aug. '89)
(Random walks in electric networks)

* *Topic(s) of formal seminar(s)/ colloquium lecture(s) given, if any, apart from informal discussions and lectures*

RAM P. SRIVASTAV, State University of New York, Stony Brook, USA (7 Aug. '89)
(Analysis and Computing)

HARRY D'SOUZA, University of Michigan-Flint, Flint, USA (7 Aug. - 30 Nov.'89)
(Algebraic surfaces)

S.R.S. VARADHAN, Courant Institute, New York University, New York, USA (10 Aug. '89)
(Entropy methods in scaling limits)

A. SRIVASTAV, TIFR, Bombay (21 - 28 Aug.'89)

LAKSHMIBAI, Northeastern University, Boston, USA (21 Aug. - 1 Sep. '89)

DINAKAR RAMAKRISHNAN, California Institute of Technology, California, USA (24 Aug. '89)
(Modular forms and Galois representations)

R.E. AMRITKAR, Poona University, Poona (21 - 27 Aug.'89)
(Exponential dimensions in multifractals; Ballistic driven aggregates)

J.P. DEMAILLY, University de Grenoble, France (1 - 5 Sep.'89)
(Transcendental proof of a generalized Kawamata-Ramanujan-Vichweg vanishing theorem;
Holomorphic Morse inequalities)

J. PASUPATHY, CTS, Indian Institute of Science, Bangalore (5 Sept '89)
(Gaussian Toeplitz matrix)

DAVID SINNOU, Institute Henri Poincare, France (7 Sep. '89)
(Torsion and points on Abelian varieties - A survey)

G.K. SANKARAN, Cambridge University, England (22 Sep. '89)
(Terminal singularities and geometry of numbers)

ASHOK SUBRAMANIAN, Stanford University, USA (24 - 26 Sep. '89)
(Complexity of circuit value and network stability)

J. KUPSCH, Department of Physics, University of Kaiserslautern, West Germany (25 Sep.'89)
(Functional integration for Euclidean fermions)

H.J.W. MULLER-KIRSTEN, Department of Physics, University of Kaiserslautern, West Ger-
many (26 Sep. '89)
(Construction of some model theories with stable or metastable pseudo particle solution)

P.N. SRIKANTH, TIFR Centre, IISc, Bangalore (27 and 28 Sep.'89)
(An application of Morse theory to ordinary differential equations)

ARUN VARMA, Department of Mathematics, University of Roorkee (9 - 14 Oct.'89)

N. MUKUNDA, CTS, Indian Institute of Science, Bangalore (23 Oct.'89)
(A look at the relationship between Physics and Biology)

C. PANDURANGAN, Department of Computer Sciences and Engineering, IIT, Madras
(26 Oct.'89)
(Reduction in algorithms)

LABASSE, University of Paris, Paris, France (17 Nov.'89)
(Introduction to Langland's philosophy)

E. PENAKHOV, Institute of Mathematics and Mechanics, Baku, USSR (23 Nov.'89)
(Some problems in inverse spectral theory; An inverse problem in theory of potentials)

P.P. SCHMIDT, Office of Naval Research, Washington, USA (22 - 23 Nov.'89)
(Atom transfer problems in vibrational spectroscopy)

V. RADHAKRISHNAN, Raman Research Institute, Bangalore (28 Nov.'89)
(Of wind and water-Story of sailboats)

A.P. BALACHANDRAN, Syracuse University, USA (27 Nov. - 1 Dec.'89)
(Spin-statistics theorem or a use of the antiparticle)

C. PUTTAMADIAH, Department of Mathematics, University of Mysore, Mysore (28 Nov.
2 Dec.'89)

BISWAJYOTI DEY, Plasma Research Institute, Gandhinagar (4 - 6 Dec.'89)
(Chaos in some field theoretic models)

DIPTIMAN SEN, C.T.S. Bangalore (4-6 Dec.'89)
(Conformal field theory and statistical physics)

M.J. LIGHTHILL, University College, London, U.K. (5 Dec.'89)
(Recent fluid mechanical discovery by biologists)

C.ISO, Institute of Technology, Tokyo, Japan (14 Dec.'89)
(Secondary particle multiplicity distribution in high energy collisions)

DIPANKAR CHATTERJEE, Viswa Bharati, Santiniketan (14 - 18 Dec.'89)

MUSTANSIR BARMA, TIFR, Bombay (17 - 18 Dec.'89)
(Phase transitions in the Falicov-Kimball model)

S. DATTA GUPTA, Jawaharlal Nehru University, Delhi (17 - 22 Dec.'89)
(Dynamics of a supercooled liquid; Quantum dissipations in 2-level systems)

I. ANTONIADIS, Ecole Polytechnic, Paris, France (21 Dec.'89)
(Strings in expanding universe)

JEEVA S. ANANDAN, Department of Physics, University of South Carolina, USA (23 - 27 Dec.'89)

(Geometric view of quantum mechanics)

V. PATI, Indian Statistical Institute, Bangalore (25 - 31 Dec.'89)

(Heat kernel trace estimates on algebraic threefold singularities)

V.S. SUNDAR, Indian Statistical Institute, Bangalore (29 Dec.'89)

(Commuting squares and subfactors)

M. BHASKARAN, Part-time Academic College of Advanced Education, Church Lands, West Australia (31 Dec.'89 - 19 Jan'90)

RAVI KANNAN, Carnegie-Mellon University, Pennsylvania, USA (4 Jan.'90)

(Feobenius problems; Postage stamp problem)

K.S. NARAIN, CERN, Geneva, Switzerland (5 Jan.'90)

(Coulomb gas approach for SU(2) parafermions)

SANJAY JAIN, Brown University, USA (7 Jan.'90)

(Statistical mechanics of strings)

DAVID GROSS, Princeton University, Princeton, New Jersey, USA (14 - 16 Jan'90)

(Non-perturbative string theory)

JEEVA ANANDAN, University of South Carolina, USA (16 Jan.'90)

(Geometric phase in dipole interaction)

DEEPAK KUMAR, Jawaharlal Nehru University, Delhi (17 - 18 Jan.'90)

(Relaxational dynamics of planar spin system; Mode condensation in disordered systems)

D. EMMANUEL BOSCO, Regional Research Lab., Trivandrum (15-31 Jan.'90)

(Mathematical problems of random coverages in electro-crystallisation; Some noise sources in electrocrystallisation - A nonlinear transformation analysis)

RASHBA, Landau Institute of Moscow, Moscow, USSR (19 Jan.'90)

(Theory of non-radiative transitions in solids)

J.P. CARBOTTE, Department of Physics, McMaster University, Canada (21 - 24 Jan.'90)

(Superconductivity in high- T_c oxides)

DANIEL L. SETH, Ames Lab., Iowa State University, Iowa, USA (27 Jan. - 3 Feb.'90)

M. MUTHUKUMAR, University of Massachusetts, Polymer Research Institute, USA (1-4, 7, 9-16 Feb. '90)

(The field theory of polymers)

M.J. BECKMANN, Technical University, Munich, FRG, and Brown University, USA (7 Feb.'90)

(Dynamic programming)

ABHIJIT MUKHERJEE, S.N. Bose National Centre for Basic Sciences, Calcutta (16 Feb.'90)
(Transmittance in disordered systems)

Fourteen Russian delegates from Soviet Union (26 Feb.'90)

APOORVA D. PATEL, Indian Institute of Science, Bangalore (28 Feb.-3 March '90)

ALFRED ACTOR, Physics Department, Pennsylvania State University, USA (1 - 5 March '90)
(Casimir phenomena)

B. ANANTHANARAYAN, School of Physics, University of Hyderabad, Hyderabad (8 March '90)
(Topics in three generation superstring theories)

V. SRINIVASAN, School of Physics, University of Hyderabad, Hyderabad (8 March '90)
(Thermofield dynamics approach to master equations)

G.I. ARKHIPOV, A.A. KARATSUBA and K.I. OSKOLVKOV, USSR (11 - 20 March '90)

T. SUNADA, Nagoya University, Nagoya, Japan (13 March'90)
(Riemann hypothesis in spectral geometry)

BOUTET DE MONVEL, University of Paris VI, Paris, France (22 March '90)
(Logarithmic potential for the Schrodinger equations)

L. BRAMBILA PAZ, University of Mexico, Mexico (27 March'90)
(Modulii of vector bundles with endomorphisms)

ASHOKE SEN, TIFR, Bombay (24 - 28 March'90)
(Background independence of string field theory)

AVINASH DHAR, TIFR, Bombay (25 March - 1 April '90)
(Two dimensional quantum gravity)

C.S. AULAKH, Institute of Physics, Bhubaneswar (27 March - 1 April '90)
(Gaussian rational conformal field theories)

Mathematics Colloquium Lectures

C. Adimoolam	:	Quantum groups
M.S. Raghunathan	:	Algebraic groups and simple groups
K.K. Mukherjee	:	Lefschetz theory for manifolds with boundary .
S.R.S. Varadhan	:	Entropy methods in scaling limits
Dinakar Ramakrishnan	:	Modular forms and Galois representations

David Sinnou	:	Torsion and points on Abelian varieties - A survey
G.K. Sankaran	:	Terminal singularities and geometry of numbers
R. Balasubramanian	:	Pseudoelliptic prime numbers
C. Pandu Rangan	:	Reduction in algorithms
Krishna Maddaly	:	Anderson model with decaying couplings - extended states
Labasse	:	Introduction to Langlands philosophy
R. Ramanujam	:	Decidability of some logics for concurrency
E. Penakhov	:	Some problems in the inverse spectral theory; An inverse problem in the theory of potentials
Madhavan Mukund	:	Infinite games
Kamal Lodaya	:	An axiomatization of trees
Ravi Kannan	:	Frobenius problem (Postage stamp problem)
C.S. Yogananda	:	Exponential sums
Boutet De Monvel	:	Logarithmic potential for the Schrodinger equations
L. Brambila Paz	:	Modulii of vector bundles with endomorphisms