RAMAN RESEARCH INSTITUTE
BANGALORE 560 080

ANNUAL REPORT 1987-88

Introduction

The Raman Research Institute founded by Prof. C.V. Raman in the late forties was reorganised, after his death in 1970, as a national Institute for research in basic science and it has been receiving generous grants from the Department of Science and Technology of the Government of India since 1972. The main fields of research are Astronomy and Astrophysics, and Liquid Crystals.

1. Astronomy and Astrophysics

Astronomy which is one of the oldest sciences is concerned with the study of heavenly bodies by investigating the radiation received on earth from them. Optical astronomy deals with the "visible" part (wavelength 3000 Angstroms to 6500 Angstroms, 1 Angstrom = 10^{-8} centimeter) of the electromagnetic spectrum. Radio Astronomy, which had its beginnings in 1932 also deals with the study of these heavenly bodies, but the radiation received by radio telescopes on earth is in the radio wavelength part (30 meters to 1 millimeter) of the same electromagnetic spectrum. The lower and upper limits in wavelength of the radio spectrum are set by the earth's atmosphere and ionosphere respectively. In spite of these limitations, the radio window is very wide (30,000 to 1 compared to the 2:1 wavelength ratio in the visible part) and studies within it over the years have yielded information leading to many exciting discoveries such as the $3^{o}K$ cosmic background radiation, quasars, pulsars, etc.

The Raman Research Institute has observational programmes in Radio Astronomy extending over most of the available radio spectrum. It has set-up a Decameterwave Radio Telescope at Gauribidanur jointly with the Indian Institute of Astrophysics. Operating at a wavelength of 10 meters, it is among the largest telescopes in the world and is being used to study the radio emission from various types of celestial objects such as the Sun, Jupiter, radio sources of various kinds in our Galaxy, and external Galaxies. Moving to somewhat shorter wavelengths, members of the Institute use the Ooty Radio Telescope operated by the Tata Institute of Fundamental Research, Bombay. This instrument operates at a wavelength of approximately 1 meter and is used for carrying out observations of pulsars, and nebulae of various kinds in the Galaxy.

During the past two decades, millimeterwave astronomy has assumed great importance because of the discovery of numerous molecules (combinations of Hydrogen, Carbon, Nitrogen, Oxygen, Silicon, etc.) by their emitted line radiations in the shortest wavelength region of the radio spectrum. These molecules are generally found in dense molecular clouds in our own and other Galaxies where star formation is thought to be taking place. The Raman Research Institute has set-up two millimeterwave telescopes of diameters 1.5 and 10.4 meters, which are used for the study of these radiations.

In addition, the Institute has theoretical research programmes in many branches of Astrophysics like Pulsars, Supernova Remnants, the interstellar medium, Galaxies and several aspects of General Relativity and Gravitation.

2. Liquid Crystals

Liquid Crystals are states of matter intermediate between the liquid and crystalline states. Many organic compounds whose molecules have pronounced shape anisotropy exhibit such phases. The unique combination of fluidity and anisotropic properties of liquid crystals has led to many applications of these materials. The Liquid Crystals Laboratory of the Raman Research Institute has contributed significantly to the development of the field over the past decade and a half.

The laboratory has been organised to undertake studies of most of the fundamental properties of liquid crystals. Theoretical and experimental work on liquid crystals is continuing along the lines indicated in the reports of previous years.

A somewhat more technical account of the work carried out in the past year is given in the following.

1. Theoretical Physics and Astrophysicis

Quantum Measurement: During investigation of the transition between quantum and classical behaviour of physical systems, an interesting relation was found between Zurek's 'Pointer Basis' and the 'Coherent State Basis' systems like the harmonic oscillator and a large spin. The relation is being explored further.

Geometric Phase: The phenomenon of Berry's phase in quantum mechanics was studied both theoretically and experimentally. An

optical experiment with a laser interferometer was performed which demonstrates the effect of geometric phase.

On the theoretical side, some ideas of Pancharatnam on the polarization of light were carried over to quantum mechanics to arrive at a general setting for Berry's phase. It is shown that Berry's phase also appears in noncyclic evolution and in quantum measurements.

Gravitational Instantons: A new formulation of general relativity was earlier reported which led to a simplification of the Einstein equations. Using this new formulation, an Ansatz was found which led to a class of exact solutions which are gravitational instantons and represent tunnelling between the different vacuua of the quantum theory.

Geometry of Killing Trajectories and Black Holes in higher dimensions : The Frenet-Serret formalism applied earlier to study Killing trajectories in five and six dimensions has been extended to higher dimensions. The curvature and higher torsions are expressed in terms of an effective field strength and their interrelation exhibited by the use of the Cayley-Hamilton theorem. This generalises to higher dimensions the relationship of the intrinsic geometry of killing trajectories and black hole event horizons.

Quasi Normal Modes (QNM) of Black Holes : A method to study QNM's analytically is proposed. As a first step we have simulated the black hole equivalent potentials associated with

zero-mass fields of different spins in the Schwarzschild case by patching up potentials which can be solved analytically.

Studies in Stellar Dynamics : The nature of relaxation (approach to a steady state) in a collisionless self gravitating system of particles was investigated. Contrary to an idea recently expressed in the literature, the entropy and functions analogous to it do not in general increase monotonically, as shown by a simple counterexample.

Collisionless relaxation processes can be strongly influenced by approximate invariants of the time dependent potential. One such invariant (which is exact for a time dependent oscillator in one dimension) is being investigated further.

For some self gravitating systems such as globular clusters, the evolution over long time scales is due to collisions (in the sense of two-body encounters). A model for the collisional evolution of a differentially rotating disc of stars in a galactic nucleus was investigated. For a simplified collision term, both the moment equations and the transport equation have been solved. Locally, the disc evolves in a self similar manner with the thickness growing as the fourth root of time. An application to the nucleus of the nearby galaxy M31 was attempted.

Astronomical Imaging : Various schemes have been proposed for restoring phase information in optical speckle interferometry. A

comparative study of these methods had been taken up with special emphasis on low light levels where photon noise plays a dominant role.

The origin of circular polarization from pulsars: The circular polarization of the radiation from pulsars has posed a mystery for long. A new correlation found between the circular and linear signatures in the polarization patterns for a number of pulsars promises to throw light on the emission mechanisms.

2. Radio Astronomy

Noise in synthesis in very strong sources: An investigation of the response of aperture synthesis telescope in very strong sources was carried out, as an understanding of this problem appears to be of importance for several types of radioastronomical measurements. Further work is continuing.

Decameter Wave Astronomy:

The construction and testing of an array of 64 Yagi antennas located at a distance of 450 meters from the center of the EW array in the northerly direction is complete.

A map of the entire observable sky at Gauribidanur at 34.5 MHz has been completed using the digital correlation receiver. Procedures to remove the instrumental response (Clean) in such a large scale map have been evolved and successfully used. Calibration of the map is under progress.

Sun : Observations in the range 30-70 MHz were used to derive the spectrum and its variations of the low frequency radio emission

from the Sun. High time and frequency resolution studies of transient radio bursts from the Sun are continuing.

Galaxy : Observations of some selected regions of the galactic plane are being made using the North extension array in conjunction with the EW and S arms of the T antenna. This should improve the resolution in declination of the maps by a factor of two.

Radio Sources : Scintillation observations of some selected sources using the T antenna in the tracking mode are being continued. Power spectral analysis of the data obtained to detect IPS is in progress. A data base of about a year is necessary for this purpose.

Observations were attempted with the Compound Grating interferometer on some galactic and extragalactic sources to study the one dimensional structure with 3 arc minute resolution. Variations in phase resolution at 34.5 MHz encountered during preliminary trials were traced to both ionospheric propagation effects and the system configuration. New observational procedures are being adopted and analysis of the data is in progress.

Pulsars : A comparison of the data obtained at 34.5 MHz with the 25 MHz observations at Kharkov showed that the energy spectra at features beyond the main pulsar window must be very steep. This may have interesting implications for the orientation of the magnetic dipole with respect to the rotation axis form these neutron stars.

Millimeter wave Astronomy

Considerable software development was carried out during the year to partially automate the calibration and observation procedures using a chopper wheel and beam-switching system.

SiO observations were carried out using the cooled receiver. About 150 late type stars were surveyed for emission in the SiO maser line at 86 GHz. Several known sources were found to have intensities different from previous observations implying variations with time. New objects emitting this spectral line were also found. Observation of some selected sources for time variations is in progress.

Instrumentation

Decameter: A data logging system capable of recording 12-bit data at a rate of 30 microseconds per sample was built and tested. This unit will be used with the existing analog and digital receiver systems.

An 8-channel analog receiver suitable for a variety of observations was also built and tested.

Design and development of a single 512 channel Data Acquisition System which acts as a preprocessor for line observations using the filter bank receiver is under progress.

The design of a two bit 4 level 1024 channel digital correlation receiver for spectral line observations using the Gauribidanur 'T' array has been completed. The local Oscillator system required for observing 8 spectral lines simultaneously has been designed and tested. Attempts to estimate spectral line widths and intensities in various directions is under progress.

Mauritius: Design optimization of Helical antennas for the Mauritius Radio Telescope has been taken up. The antenna is designed to work at 150 MHz with an effective collecting area of at least one wavelength squared, capable of operating over an octave bandwidth.

Millimeter: An ultra-wideband mechanically tunable solid-state local oscillator was developed to cover the frequency range of 80 to 116 GHz to observe different species of spectral lines by merely tuning the local oscillator.

A new focus platform was fabricated and erected to facilitate access to the secondary mirror.

3. Liquid Crystals

Work is continuing on various aspects of the physics, chemistry and technology of liquid crystals. It has been a fruitful year, during which a number of fundamentally important observations have been made. A very brief summary of some of the more significant results is given below.

Biaxial nematic liquid crystals : The biaxial nematic (N_b) phase is attracting the attention of condensed matter physicists at present, and many interesting theoretical predictions have been made. However none of these ideas have yet been verified because no convenient systems are available for experimental study. The suggestion was made by one of us a few years ago (Plenary Lecture, X Int. Liq. Cryst. Conf., York, 1984) that a convenient way of obtaining the N_b phase in a simple low molecular weight thermotropic system is by 'bridging the gap between rod-like and

disc-like mesogens'. We succeeded in preparing such molecules - copper complexes which form paramagnetic nematic liquid crystals. Careful conoscopic studies have since been made which establish the occurrence of the N_b phase in these complexes. (Independently Malthete et al have reported the N_b phase in another compound, which again combines the features of the rod and the disc. However, contrary to the predictions of statistical models, N_b phase of this compound has been reported to occur at a higher temperature relative to the uniaxial phase, N_u.) We have demonstrated the biaxiality of the nematic phase, observed the $I - N_u - N_b$ sequence of transitions, and the dependence of the biaxiality on temperature.

Paramagnetic nematic liquid crystals : The copper complexes referred to above also represent the first examples of molecules that form paramagnetic nematic liquid crystals. An interesting problem that needs to be studied is the magnetic order in this phase, and the possibility of its coupling with the nematic order. Very recent ESR experiments by Eastman et al on a discotic copper complex indicate that single crystals form a one dimensional spin 1/2 Heisenberg antiferromagnet and that in the discotic phase the exchange interactions are still significant and a degree of long range order persists. It is therefore conceivable that a certain measure of antiferromagnetic short range order is present in the nematic phase as well. Further studies are in progress.

The Lehmann rotation phenomenon : The famous rotation phenomenon in cholesteric droplets described by Lehmann in 1900, which has

eluded skilled experimentalists for nearly 90 years, has been reproduced for the first time in this laboratory, using an electric field instead of a thermal gradient. The following results have been established: (a) All the drops rotate in the same direction for a given sense of the field. When the voltage is reversed, the sense of rotation is reversed. (b) The angular velocity increases linearly with applied voltage up to $\approx$ 3.5 V beyond which the structure of the drop changes and the rotational velocity becomes a non-linear function of the applied voltage. (c) Nematic drops do not rotate under the action of **E**. (d) When the handedness of the helix is reversed, the angular velocity also reverses sign for any given sense of the field **E**. (e) The angular velocity does not depend on the radius of the drop, showing that it is the structure that rotates and not the drop as a whole. (f) Though the angular velocity is roughly of the same magnitude in all drops, some drops which touch either a glass plate or a dust particle rotate with a lower velocity.

Flexoelectricity and electrohydrodynamic instability : A one-dimensional theory is developed of electrohydrodynamic instabilities in nematics under AC excitation by incorporating the flexoelectric terms. The results account for the following observations which were not adequately explained earlier: (1) The occurrence of oblique rolls (OR) at a threshold voltage $V_{th}(\nu)$ upto a certain well defined frequency ν_o which depends on the conductivity of the sample. (2) The occurrence of OR at voltages $> V_{th}$ at which normal rolls are seen for some frequency range $\nu_c > \nu > n_o$. (3) The observation of 'chevrons' in the

dielectric regime. (4) The occurrence of 'longitudinal' rolls with a field threshold for materials with negative dielectric anisotropy close to the nematic-smectic transition point.

Studies on smectics:

(a) An incommensurate smectic A phase (the first ever incommensurate phase to be observed in a fluid system) was discovered in this laboratory and reported three years ago. This was identified to be a 'weakly coupled' incommensurate phase. A second type of incommensurate phase - a strongly coupled one - has now been discovered in a binary liquid crystal system. Xray diffraction studies of this phase show that the two incommensurate density waves are modulated in one-dimension (i.e., along the director) leading to the existence of 'solitons'. On decreasing the temperature the soliton periodicity diverges leading finally to an incommensurate-commensurate transition. These results are in agreement with the prediction of the phenomenological theory of frustrated smectics.

(b) A smectic A - smectic C* tricritical point (TCP) has been observed. Very precise Xray studies carried out on the second order side of TCP show that the 'mean field range' shrinks as TCP is approached. It is also shown that this TCP is likely to be a Landau- type of tricritical point.

(c) A high resolution temperature-concentration diagram and detailed DSC data have been obtained near an expected smectic A_d - reentrant nematic - smectic A_1 bicritical point. These studies, which were undertaken since doubts have been raised about the existence of such a bicritical point on theoretical grounds, show

that the bicritical point has split into a critical end point and a tricritical point. Although such a situation has been predicted in magnetic systems, it has not so far been envisaged by any of the existing theories on liquid crystals.

(d) The first instance of a pressure-induced triply reentrant phenomenon has been reported.

Crystal Structure Analysis of a Discotic Complex : The crystal structure of a disc-like mesogen has been solved by Xray diffraction methods for the first time. The molecule is an organometallic copper complex that exhibits the discotic phase. The structure was solved by direct methods and refined to R = 0.097 by the structure factor least squares procedure.

New materials : New compounds exhibiting the ferroelectric chiral smectic C phase have been prepared. A suitable mixture using these compounds provides a fairly low temperature ferroelectric liquid crystal. The spontaneous polarisation has also been measured as a function of temperature.

Applications : Analysis is in progress of hardware complexity vs. improved performance of the hybrid addressing techniques for multiplexing LCDs. Preliminary studies have also started on new types of LCDs, e.g., supertwist birefringence device, surface stabilized ferroelectric device, etc.

The work done jointly with BEL in setting up a manufacturing facility, based on knowhow developed by us, is beginning to yield tangible results. BEL's sale of LCDs was nearly Rs.10.00 lakhs during 1987-88 and is expected to increase significantly in the next few years.

Advanced training in research is being offered to the following teachers from other organizations.

Name	Topic of Study	
S. Somasekhara Vijayanagar College Hospet	Experimental studies of phase diagrams of liquid crystals	UGC Faculty Improvement Programme
C. Nagabhushan Veerashaiva College Bellary	Experimental studies on the dielectric properties of liquid crystals	
H.P. Padmini The National College Bangalore	Some physical studies on liquid crystals	
P.R. Maheswara Murthy Govt. Science College Bangalore	Electric and Magnetic Field effects in liquid crystals	

Ph. D.

N. Udaya Shankar	Application of Digital Techniques to Radio Astronomy Measurements Bangalore University	
D. Bhattacharya (Joint Astronomy Programme)	The Influence of Pulsars on Supernova Remnants Indian Institute of Science	
A.A. Deshpande	Detection and Processing of Pulsar Signals at Decametric Wavelengths Indian Institute of Technology Bombay	
S. Somasekhara	Experimental Studies of Phase Diagrams of Liquid Crystals University of Mysore	
C. Nagabhushan	Experimental Studies on the Dielectric Properties of Liquid Crystals, University of Mysore	Reports Awaited
T.N. Ruckmongathan	Some New Addressing Techniques for RMS Responding Matrix LCDs, Indian Institute of Science, Bangalore	

Publication:

The research work done by the staff of the Institute has been published in a number of journals. A list of publications that have already appeared and those submitted and in press is given at Annexure - I (Page 22).

Conferences/Seminars and Meetings

The staff of the Institute visited various institutions in India and abroad and attended conferences and presented papers. In addition, 60 lectures were given by them elsewhere.

The Institute was a co-sponsor for the International Conference on Gravitation and Cosmology held at Goa between 14th and 19th of December, 1987.

Colloquia

The scientists of the Institute and visiting scientists both from within and outside the country gave 33 colloquia at the Institute on different topics during the year.

Journal Club Meetings

Fifteen meetings were held on various topics of interest to the scientific activities at the Institute.

In-house Discussion Meeting

An in-house discussion meeting was held on 19 March 1988 on the current research activities of all groups in the Institute.

Visiting Scientists

A number of scientists from institutions within the country and outside visited the Institute during the year. Their names are listed following those of the scientific and technical staff of the Institute given towards the end of the report.

4. Library

Six hundred and forty two books were added to the book collection during the year. The total number of books now is 15949. The library subscribes to one hundred and fifty four journals and has 18971 bound volumes of journals.

General

The following grants were received from the Department of Science and Technology during the year:

	Rs. in lakhs
Recurring : Non Plan	38.00
Recurring : Plan	72.00
Non-Recurring : Plan	128.00
Total	238.00

STAFF

The scientific and technical staff of the Institute is given below. Additions during the year are marked with an asterisk.

V. Radhakrishnan
S. Chandrasekhar
S. Krishnan
G. Srinivasan+++
S. Krishna
G.S. Ranganath
R. Bhandari
B.K. Sadashiva
K.A. Suresh@
D.K. Ravindra
R.S. Arora@@@
N. Udaya Shankar
M. Modgekar
Mohd. Ateequlla
V. Lakshminarayanan
B.R. Ratna
K.R. Anantharamaiah#
A.A. Deshpande
D. Bhattacharya
Jayanthi Ramachandran
B.V. Nataraja
R. Nandakumar
N. Jayaprakash
P.N. Ramachandra
K. Sukumaran
S. Chanthrasekharan
H. Subromonyam
G. Rengarajan
P.S. Sasi Kumar
P.S. Ram Kumar
R. Vijayalakshmi
L. Saira
K. Ramesh Kumar

Joinst Astronomy Programme

S. Karbelkar
S. Sridhar
Nimesh Patel
B. Ramesh
T.K. Sridharan

S. Ramaseshan
N.V.G. Sarma+
C.V. Vishveswara++
N.V. Madhusudhana
R. Shashidhar
R. Nityananda
C.S. Shukre
U.D. Kini
V. Surendranath@@
M. Selvamani
T.N. Ruckmongathan
K. Smiles Mascarenhas
T. Ramachandran
C. Ramachandra Rao
B.R. Iyer
J. Samuel
M. Vivekanand##
K.S. Dwarakanath
B.S. Srikanta
P.A. Johnson
R. Ganesan
T.S. Ravishankar
M.R. Subramanyam
K. Subramanya
P.G. Ananthasubramaniam
P.S. Somasundaram
Antony Joseph
G. Sarabagopalan
K. Chandrasekhara
G. Jayakumar
V. Suresh Rao
Chitra M. Gokhale
D. Baranidharan

Resignations

C.J. Pasupathi
Ganesan Radhakrishnan

Consultant Physicians

A.R. Pai
M.R. Baliga

Research Fellows:

S. Krishna Prasad
R. Pratibha
V.A. Raghunathan
Geetha G. Nair
Jyotsna Rajan
K. Meena Kumari*
D.S. Shankar Rao*
Rani P. Rao
V.N. Raja
K. Usha
G.B. Sivakumar
H.P. Subramanya*
Archana Ghode*
P.B. Sunil Kumar*

+ On leave with CSIRO Division of Radiophysics, Sydney, Australia.

++ On deputation as Director, Bangalore Planetarium, Bangalore.

+++ On leave with European Southern Observatory, Munich, West Germany.

@ On leave with Carnegie-Mellon University, Pittsburgh, U.S.A.

@@ On leave with Kent State University, Ohio, U.S.A.

@@@ On leave with National Radio Astronomy Observatory, Tucson, Arizona, U.S.A.

On leave with National Radio Astronomy Observatory, Socorro, New Mexico, U.S.A.

On leave with Institute de Radio Astronomie Millimetrique, Grenoble, France

LIST OF VISITORS:

1.	Dr. M. Longair Royal Observatory Edinburgh, U.K.	April 14 - April 18, 1987
2.	Dr. L. Pagani Observatoire de Paris Meudon, France	June 10 - July 19, 1987
3.	Dr. S. Chakrabarti CALTECH, Pasadena California, U.S.A.	July 17 - July 22, 1987
4.	Dr. Tevian Dray Oregon State University Corvallis, U.S.A.	August 3 - August 19, 1987
5.	Dr. Corinne Manogue Oregon State University Corvallis, U.S.A.	August 3 - August 19, 1987
6.	Dr. J.L. Osborne Dept. of Physics University of Durham Durham, U.K.	August 4 - August 13, 1987
7.	Dr. B. Bertotti University of Pavia Pavia, Italy	October 4 - October 10, 1987
8.	Dr. Y. Maudarbocus The University of Mauritius Redult, Mauritius	October 26 - November 11, 1987
9.	Dr. A. Krasinski N. Copernicus Astronomical Centre, Warsaw, Poland	November 27 - December 7, 1987
10.	Dr. J. Nelson INFN Sezione di Torino Torino, Italy	December 6 - December 11, 1987
11.	Dr. T. Rothman Princeton, U.S.A.	December 7 - December 13, 1987
12.	Dr. C.J.S. Clarke Faculty of Math. Studies University of Southampton Southampton, U.K.	December 9 - December 12, 1987
13.	Dr. J. Hartle Physics Department University of California Santa Barbara, U.S.A.	December 10 - December 13, 1987

14.	Dr. J. Friedman Department of Physics University of Wisconsin Wisconsin, U.S.A.	December 20 - December 23, 1987
15.	Dr. M. Demianski University of Warsaw Warsaw, Poland	December 20 - December 27, 1987
16.	Dr. R. Sorkin University of Syracuse Syracuse, U.S.A.	December 20 - December 28, 1987
17.	Dr. J. Winicour University of Pittsburgh Pittsburgh, U.S.A.	December 21, 1987 - January 1, 1988
18.	Sir Hermann Bondi Master Churchill College London, U.K.	December 26, 1987 - January 5, 1988
19.	Dr. B. DeWitt Department of Physics University of Texas Austin, U.S.A.	January 5 - January 7, 1988
20.	Dr. C. DeWitt Department of Physics University of Texas Austin, U.S.A.	January 5 - January 7, 1988
21.	Dr. Lee Smolin Department of Physics Yale University New Haven, U.S.A.	January 6 - January 11, 1988
22.	Dr. V. Chandrasekharan Directeur de Recherches C.N.R.S., Paris, France	January 7 - January 9, 1988
23.	Dr. E.F.J. Ehlers Max Planck Institute for Physics & Astrophysics Garching bei Munchen West Germany	January 20 - January 24, 1988
24.	Dr. Ian Percival Queen Mary College London, U.K.	January 25 - February 1, 1988
25.	Dr. Ornella Pantano SISSA, Trieste, Italy	February 15 - February 20, 1988

26.	Dr. Joanna Rankin University of Vermont Vermont, U.S.A.	February 18 - March 29, 1988
27.	Dr. Alexandar Mologianu Space Research Institute USSR Academy of Sciences Moscow, U.S.S.R.	March 1 - March 24, 1988
28.	Dr. Vassili Velichov Space Research Institute USSR Academy of Sciences Moscow, U.S.S.R.	March 1 - March 24, 1988
29.	Dr. Matveyenko Leonid Space Research Institute USSR Academy of sciences Moscow, U.S.S.R.	March 1 - March 12, 1988
30.	Dr. Leonid Kogan Space Research Institute USSR Academy of Sciences Moscow, U.S.S.R.	March 1 - March 24, 1988
31.	Dr. J.A. Gil Instytut Fizyki Rzeszow, Poland	March 13 - April 3, 1988

ANNEXURE - I

PUBLICATIONS

1. Observation of topological phase by means of a laser interferometer. (Rajendra Bhandari and Joseph Samuel) - Phys. Rev. Lett., **60**, 1211 (1988).

2. Exact solutions for spacetimes with local rotational symmetry in which the Dirac equation separates. (B.R. Iyer and C.V. Vishveshwara) - J. Math. Phys., **28**, 1377 (1987).

3. The geometry of Killing trajectories and black holes in higher dimensions. (B.R. Iyer and C.V. Vishveshwara) - International Conference on Gravitation and Cosmology, Goa (1987).

4. Atmospheric noise on the bispectrum in optical speckle interferometry. (S.N. Karbelkar) - J. Astrophys. Astr., **8**, 271-274 (1987).

5. Spinning cosmic strings and quantization of energy. (J. Samuel and B.R. Iyer) - Phys. Rev. Lett., **59**, 2379 (1987).

6. A general setting for Berry's phase. (J. Samuel and Rajendra Bhandari) - Phys. Rev. Lett., **60**, 2339 (1988).

7. Do H-functions always increase during violent relaxation? (S. Sridhar) - J. Astrophys. Astron., **8**, 257 (1987).

8. The progenitors of pulsars. (G. Srinivasan and D. Bhattacharya) - in proceedings of IAU Symposium No. 125: Origin and Evolution of Neutron Stars, eds. D.J. Helfand and J.H. Huang, D. Reidel, Dordrecht (Netherlands), 109-119 (1987).

9. Some recent developments in general relativity. (C.V. Vishveshwara) - in proceedings of the National Symposium on Recent Developments in Theoretical Physics, Kottayam (1986), eds. E.C.G. Sudarshan, K. Srinivasa Rao and R. Sridhar (1987).

10. Newton, Einstein and Gravitation. (C.V. Vishveshwara) - in proceedings of the seminar on 300 years of Newton's Principia, Bangalore. eds. Shashi Kant Shrivastava and N. Mukunda (1986).

11. Modern Technology and its Influence on Astronomers. (V. Radhakrishnan) - in Modern Technology and its Influence on Astronomy, eds. A. Boksenberg and J. Wall, Cambirdge Uni. Press, Cambridge, 1987.

12. Pulsar radio luminosity laws. (V. Radhakrishnan and C.S. Shukre) - Bul. Astr. Soc. India, , (1987).

13. Research with Style. (S. Ramaseshan) - Ind. J. Pure & Applied Phy., **26**, 1988.

14. Paramagnetic nematic liquid crystals. (S. Chandrasekhar, B.K. Sadashiva and B.S. Srikanta) - Invited lecture, Fifth European Liquid Crystal Conf., Borovetz, Bulgaria, March 1987 - Mol. Cryst. Liq. Cryst., **151**, 93 (1987).

15. Bend and splay elastic constants of a discotic nematic. (V.A. Raghunathan, N.V. Madhusudana, S. Chandrasekhar and C. Destrade) - Mol. Cryst. Liq. Cryst., **148**, 77 (1987).

16. Electromechanical coupling in cholesteric liquid crystals. (N.V. Madhusudana and R. Pratibha) - Mol. Cryst. Liq. Cryst. Lett., **5**, 43 (1987).

17. Flexoelectric origin of oblique-roll electrohydrodynamic instability in nematics. (N.V. Madhusudana, V.A. Raghunathan, K.R. Sumathy) - Pramana, J. Phys., **28**, L311 (1987).

18. Smectic A_d - smectic A_2 critical point. (R. Shashidhar, B.R. Ratna, S. Krishna Prasad, S. Somasekhara and G. Heppke) - Phys. Rev. Lett., **59**, 1209 (1987).

19. Evidence of a first order smectic A - smectic C* transition and its approach to tricritical behaviour. (B.R. Ratna, R. Shashidhar, Geetha G. Nair, S. Krishna Prasad, Ch. Bahr and G. Heppke) - presented at the First Int. Symposium on Ferroelectric Liquid Crystals, Arcachon, September 1987 - Phys. Rev. A (Rapid Communication), **37**, 303 (1988).

20. Dipole-dipole interactions in swallow-tailed liquid crystalline mixtures. (H. Kresse, W. Weissflog, C. Nagabhushan and R. Shashidhar) - Phys. Stat Sol. (a)**101**, K77 (1987).

21. Dielectric studies on two compounds exhibiting first and second order smectic A - nematic transitions. (G. Heppke, S. Pfeiffer and R. Shashidhar) - Mol. Cryst. Liq. Cryst. Lett., 5, 106 (1987).

22. A new alternative for the smectic A_d - reentrant nematic - smectic A_1 bicritical point. (V.N. Raja, R. Shashidhar, B.R. Ratna, G. Heppke and Ch. Bahr) - Phys. Rev. A (Rapid Communication), **37**, March 1988.

23. Antiparallel ordering of molecules in liquid crystalline swallow tailed compounds. (C. Nagabhushan, B.R. Ratna, R. Shashidhar, S. Chandrasekhar, H. Kresse and W. Weissflog) - Mol. Cryst. Liq. Cryst. Lett., 5, 87 (1988).

24. An incommensurate smectic A phase. (B.R. Ratna, R. Shashidhar and V.N. Raja) - Incommensurate Crystals, Liquid Crystals and Quasi Crystals, Eds. J.F. Scott and N.A. Clark (Plenum Press, 1987), p. 259.

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