RAMAN RESEARCH INSTITUTE
BANGALORE 560 080

ANNUAL REPORT 1986-87

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 exihibit 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 Astrophysics**

Optical Interferometry: A comparative study of various phase recovering methods in optical interferometry was undertaken with particular emphasis on speckle masking interferometry.

Stellar dynamics: The evolution of a collissionless stellar system to a steady state has traditionally been described by the "violent" relaxation introduced by Lynden-Bell. More recent work has recognized that there must be many more constraints on this process. For instance, the distribution function must be a constant of the motion in the final steady state. Assuming that Energy is the only integral of the motion leads to a contradiction. This suggests the conjecture that there are additional constants of the motion (apart from Energy) in the steady state. While this conjecture is unproven, it is lent some support by analogous results in megnetohydrostatics. These ideas could usefully be applied to a stellar system round a central black hole.

Collisional effects of stellar discs: The possibility of star formation in the outer, vertically self gravitating regions of accretion discs was investigated. A study of the effect of drag between the stars and the gas shows that the drag becomes more effective as the relative rotation between the stars and the gas decreases, due to the strong increase of coulomb cross-sections at lower velocities. The problem of describing the intrinsic viscosity of star clusters was studied in the case where near encounters dominate. The appropriate form of the linearized transport equation has been obtained, but the full calculation may require numerical work.

Starobinsky's quasi-de Sitter model: Requiring that this cosmological model gives rise to an inflationary phase, Starobinsky obtained a constraint upon the mass parameter which appears in his model. This constraint has been rederived by a different method, using Whitt's conformal transformation which casts the theory into the form of gravity interacting with a scalar field.

Quantum cosmology: In quantum cosmology, a wave function of the universe is obtained by solving the Wheeler-De Witt equation in minisuperspace a la Hartle and Hawking. The wave function then determines a probability distribution which should obey a Fokker-Planck equation. A study of the relation between P and the solution to the Fokker Planck equation derived by Starobinsky for a universe expanding quasi-exponentially shows consistency between these two interpretations, provided long wave length quantum fluctuations are taken into account.

Chaotic inflation: It has recently been suggested by Papantonopoulos, Uematsu and Yanagida that chaotic inflation can occur in a non-linear sigma model. The non-minimal coupling of the real part and the imaginary part of a complex scalar field is supposed

automatically to give the correct initial conditions for inflation, the potential for which is provided by a soft symmetry breaking term. We show that the non-minimal coupling is not essential, although the fine-tuning in the potential is necessary.

Supernova remnants: A theoretical study has been made of the simultaneous evolution of radio brightness of the shell and the plerionic components of supernova remnants harbouring pulsars. This has led to the identification of cases where the resulting SNR has a shell, plerion or combination morphology.

SN 1987a: A model was constructed to explain the initial behaviour of the supernova SN 1987a. An attempt is underway to explain its unusual light curve by taking into account the effect of a pulsar within the expanding shell.

Neutron stars: We are continuing to study the long-term evolution of neturon star magnetic fields. The reasons behind an asymptotic lower limit of the surface dipole field is being investigated.

Pulsar radio luminosities: A comparison of pulsar radio luminosity laws showed that among those proposed the best description of the data is provided by the one in which the radio luminosity varies as the cube root of the total energy loss rate.

No-interaction theorem: A theorem was proved showing that relativistic symmetry forbids direct interaction between particles even if the particles have internal Grassmann degrees of freedom describing spin. This generalizes earlier, known results in classical mechanics to the recently discovered pseudomechanics.

Regge trajectories: Classical models of relativistic spinning particles were studied. This study showed that causality places

strong restrictions on the mass spin relationship, i.e. Regge trajectories.

Quantum gravity: A manifestly covariant Lagrangian for Ashtekar's new formulation of canonical gravity was found. This Lagrangian is polynomial in the basic fields (unlike Einstein's) and could be of some help in approaching a quantum theory of gravity.

Cosmic strings: It has been shown that contrary to the claim by Mazur, energy need not be quantised in the background of a spinning string.

Frenet-Serret formalism: The Frenet-Serret formalism has been set up in five dimensions and used to analyse the geometry of Killing trajectories. Applications to four dimensional De Sitter and five dimensional black hole solutions are in progress. In a related investigation it has also been shown that as in four dimensions the event horizon is a Killing horizon only if rotation vanishes.

De Sitter model: As a prelude to understanding the different possible quantization schemes, the Killing vectors and geodesics of the De Sitter eosmological model have been studied. This work takes advantage of the fact that the De Sitter solution may be embedded in a five dimensional Lorentzian manifold.

2. **Radio Astronomy**

Improvements to the millimeterwave telescopes: Several panels on the 10.4 meter telescope which were affected due to solar-heating during the day, were rectified and replaced. The telescope mount was enclosed in an insulating cladding to minimize tilts due to solar-heating. A beam-switch system based on the rocking of the

tertiary mirror has been incorporated which will greatly facilitate high-sensitivity continuum and spectral-line observations.

Observations of several planets, e.g. Jupiter, Saturn and Venus were carried out at 86 GHz to check telescope pointing as well as its aperture and beam efficiencies. Optical pointing checks were also made by mounting a 3" Questar on the telescope and observing several bright stars.

A cooled Schottky-receiver operating at 20 K in a cryogenic dewar and covering the frequency range 80-115 GHz has been installed in the telescope receiver-cabin. The receiver uses a compact quasi-optical diplexer for coupling the local oscillator signal. It also incorporates a quasi-optical feed system using lens corrected corrugated horn for the efficient illumination of the primary reflector. All sub-systems of the receiver, including quasi-optical components were developed and fabricated at RRI. Noise-temperature measurements carried out on this receiver gave a DSB noise-temperature around 250K, which is a factor of two lower than the earlier room-temperature receiver.

A wide-band acousto-optic spectrometer constructed for RRI by the Meudon Observatory, Paris has been installed and interfaced with the computer. The spectrometer has 150 MHz total bandwidth, 1760 channels and an effective resolution of about 200 KHz. Data-acquisition software for this machine has been developed and tested. It will be used as the back-end spectrometer for the CO receiver operating around 115 GHz.

A millimeter wave radio-astronomical technique has been developed for the determination of the height distribution of ozone in the Earth's atmosphere. It involves observation of the strong rotational transition of ozone molecule at 110.836 GHz and

model-fitting a theoretically computed line-profile to the observed data. This ground-based observational technique could be effectively employed for a round-the-clock monitoring of the atmospheric ozone and offers a low-cost alternative to the balloon and rocket-based measurements.

Decameter Wave Telescope:

Pulsars: A scheme to enable high time resolution observations of highly dispersed pulsar signals, involving a basic swept frequency dedispersion procedure was devised. It is shown that with this method higher resolution can be obtained for strong pulsar signals. Suitable observational procedures along with software algorithms, were developed for this purpose. Use of this scheme has successfully demonstrated its ability to observe pulsars having dispersion measures as high as 35 cm^{-3} pc, with high sensitivity and high resolution. The results obtained using this system include (1) measurements of average profiles for four pulsars at 34.5 MHz (PSRs 0628-28, 0834+06, 0943+10, 1919+21) with high time resolution and sensitivity, (2) a marginal detection of interpulse emission in the case of PSR 0628-28, (3) absence of significant interpulse or off-pulse emission in those cases where significant interpulse emission has been reported at 25 MHz by the Russian observers, (4) The scaling law for intrinsic pulse width as a function of frequency was shown to break do. and in one case, (PSR 0628-28), the intrinsic width at 34.5 MHz appears to be smaller than at high frequencies, and (5) it is clearly demonstrated that estimation of interstellar scattering from the observed pulse profiles at low frequencies can be unreliable and misleading.

Sun: Measurements of the total flux from the undisturbed sun at four low frequencies (36.25 MHz, 47.50 MHz, 55.50 MHz, and 64.25

MHz) using the broadband antenna system was continued. Data obtained with high time and frequency resolution on several types of radio bursts from the Sun are also being analysed.

The compound grating interferometer was used to obtain the one dimensional brightness distribution of the Sun with three arc minute resolution in the East-West direction on many days during the period May - September 1986. These observations are being used to derive the characteristics of coronal holes at heights of about 2 solar radii.

Instrumentation

Hardware to obtain maps with a zenith angle coverage of $\pm 50^{\circ}$ was installed at Gauribidanur. Test observations carried out gave very encouraging results. Detailed observations to survey the continuum radiation at 34.5 MHz were carried out during January 1987. Raw maps showing the brightness distribution of the sky in the declination range $-35^{\circ} \delta +65^{\circ}$ and spanning 24 hour R.A. range wwere made. Programmes to clean the raw maps were developed. Cleaning and further analysis are in progress.

A VAX 11/730 computer was installed at the Gauribidanur field station for data analysis. Fabrication of the interface hardware between the existing digital correlation receiver and Fourier transform system and the VAX computer was taken up.

3. LIQUID CRYSTALS

Further theoretical and experimental studies of liquid crystals are in progress and several articles and papers have been published during the current year. A very brief summary of some of the more important results is given below.

The first examples of paramagnetic nematogens have been synthesized in the laboratory. Various physical properties like the magnetic susceptibility, optical and dielectric properties of the paramagnetic copper complexes have been studied. Evidence has been found for the extremely interesting possibility of a coupling between magnetic and nematic order. Further studies on these systems are in progress.

The splay and bend elastic constants and dielectric constants of a discotic nematic liquid crystal have been measured using a truxene compound which exhibits the nematic phase between two columnar phases as a function of temperature. Interestingly, it was found that the dielectric anisotropy is positive and that the elastic constants are of the same order of magnitude as those of nematics exhibited by rod-like molecules.

The first experimental observation has been made of the electromechanical coupling in cholesteric liquid crystals. The cooperative nature of chiral interactions in such liquid crystals leads to such unusual couplings. For example, Lehmann had found in 1900 an analogous thermomechanical coupling in which a temperature gradient along the helical axis of small cholesteric drops produced a continuous rotation of the structure. In spite of attempts in several laboratories in the world over the past 2 or 3 decades, this rotation phenomenon could not be reproduced, since it requires a fully 'free' boundary condition. A special technique was devised in our laboratory to realise such a boundary condition enabling the observation of the 'electromechanical effect'.

Electrohydrodynamic instabilities of nematic liquid crystals which have negative dielectric anisotropy are well known. However, in the recent past, an unexpected 'oblique roll' structure was found at very low frequencies. A model which includes flexoelectric effects has been developed which fully accounts for the observations. Indeed clear experimental evidence for the importance of the flexoelectric effect has also been found.

It is shown that by tuning the experimentally observable critical region, singularities of the phase boundaries can be observed in the immediate vicinity of the reentrant nematic - smectic C-smetic A multicritical point. The exponents evaluated from these singularities are found to be identical to the universal exponents associated with the nematic-smectic A-smectic C multicritical point.

A gas-liquid type of critical point has been observed for the first time in liquid crystals. It has been shown that two smectic A phases, i.e. A_d and A_2 phases with different layer periodicities can coexist along a line of first order transitions which terminates at a critical point beyond which the distinction between the two phases ceases to exist. Recent renormalization group theoretical calculations have predicted that this critical point may belong to a new universality class with an upper critical dimension $(d_c) = 6$ and with anisotropic correlation length exponents.

Accurate P-V-T studies on systems exhibiting reentrant nematic phases show that the optimum density theory is substantially incorrect. Experimental evidence of the coupling between nematic and smectic ordering in systems exhibiting the reentrant nematic phase has been obtained by studying the phase diagrams of a number of systems. In every case, the tilt of the smectic A-nematic phase boundary is shown to be related to the tilt of the nematic-isotropic phase line.

Detailed density, dielectric and x-ray studies on materials exhibiting different types of smectic A-smectic A transitions have been carried out. Though the layer spacing shows a marked jump at the transition there is hardly any change in density. This indicates that there should be marked differences in the in-plane structure factors of the different A phases.

Symmetry arguments were employed to analyse the possible defect states in biaxial nematics and smectic C* systems. In particular it was found that hybrid disclinations and classical disclination of totally different structures are allowed in biaxial nematics. New types of lattice disclinations were found to be topologically permitted in smectic C* liquid crystals. A possible model for the core structure of a wedge disclination in smectic C* has also been proposed.

A statistical mechanical theory of the main chain polymeric nematic liquid crystals has been developed and the results found to compare favourably with experimental trends. Detailed calculations have been made of the periodic distortions occurring in polymeric nematic liquid crystals. The main results are:

(i) Methods of suppressing periodic distortions and measuring the splay elastic constants have been suggested, if the anchoring is rigid.

(ii) It has been shown that the imposition of a twist on the ground state is unlikely to suppress the periodic distortions, and

(iii) Certain kinds of weak anchoring may prohibit the occurrence of periodic distortions.

Several copper complexes exhibiting mesophases have been synthesized. Of these a series of bis[1-(p-n-alkylphenyl)3-(p-n-

alkoxyphenyle) propane-1, 3-dionato] copper (II) exhibit discotic phases. The structure of the mesophase shown by these complexes is being investigated.

In the applications programme, hardware complexity vs. performance of the Improved Hybrid Addressing Technique for multiplexing LCDs was analyzed. Large area LCDs were also fabricated.

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

Name	Topic of Study	
S. Somasekhara Vijaya College Hospet	Experimental studies of phase diagrams of liquid crystals	U . G. C. FACULTY IMPROVEMENT PROGRAMME
C.Nagabhushana Veerashaiva College, Bellary	Experimental studies on the dielectric properties of liquid crystals	

Ph.D. (Awarded)

S. Krishna Prasad	High Pressure Studies of Liquid Crystalline Transitions University of Mysore
M. Vivekanand	Theoretical and Observational investigations of pulsar properties. Bangalore University.

Professor S. Chandrasekhar has been visiting Cambridge University, England, as Jawaharlal Nehru Professor and Fellow of Pembroke College., for one year from 1 October 1986.

Publications

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 in Annexure - I (Page 20).

Conferences/Seminars and Meetings

The staff of the Institute visited various institutions in India and abroad and attended conferences and presented papers. In addition, 38 lectures were given by them elsewhere.

Colloquia

The scientists of the Institue and visiting scientists both from within and outside the country gave 16 colloquia at the Institute on different topics during the year.

Journal Club Meetings

Sixteen meetings were held on various topics relating to the scientific activities at the Institute.

In-house Discussion Meeting

An in-house discussion meeting was held on 14-2-1987 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.

Library

Five hundred and eighty six new books were added to the library during the year. The total book collection now is 15,307. The library presently subscribes to one hundred and fifty periodicals and has a collection of 18,131 bound volumes.

General

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

Recurring: Non Plan	Rs. 38.00 lakhs
Recurring: Plan	Rs. 73.00 lakhs
Non-Recurring: Plan	Rs.110.00 lakhs
Total:	Rs.221.00 lakhs

2. The Audited Statements of Account with the auditor's report are given in pages 29-45.

STAFF

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

1. V. Radhakrishnan
2. S. Chandrasekhar+
3. S. Ramaseshan
4. S. Krishnan
5. N.V.G. Sarma++
6. S. Krishna
7. C.V. Vishveshwara
8. N.V. Madhusudana
9. G. Srinivasan
10. R. Shashidhar
11. G.S. Ranganath
12. V. Surendranath@
13. Rajendra Bhandari
14. C.S. Shukre
15. Rajaram Nityananda@@
16. U. Devappa Kini
17. K.A. Suresh @@@
18. B.K. Sadashiva
19. D.K. Ravindra
20. R.S. Arora
21. K.R. Anantharamaiah#
22. Jayanthi Ramachandran
23. M.O. Modgekar
24. M.R. Subramanyam
25. P.N. Ramachandra
26. R. Nandakumar
27. T. Ramachandran
28. K. Subramanya
29. K. Smiles Mascarenhas
30. N. Udaya Shankar
31. M. Selvamani
32. T.N. Ruckmongathan
33. P.A. Johnson
34. B.V. Nataraja
35. G. Sarabagopalan
36. R. Ganesan
37. H. Subramoniam
38. Antony Joseph
39. G. Rengarajan
40. K.S. Dwarakanath
41. A.A. Deshpande
42. S. Chanthrasekaran
43. K. Chandrasekhara
44. P.G.Ananthasubramanian
45. K. Sukumaran
46. R. Vijayalakshmi
47. P.S. Ramkumar
48. V. Suresh Rao
49. V. Lakshminarayanan
50. Mohd. Ateequlla
51. B.R. Ratna
52. B.R. Iyer
53. Joseph Samuel
54. M. Vivekanand***
55. T.S. Ravishankar
56. G. Jayakumar
57. C. Ramachandra Rao
58. N. Jayaprakash
59. C.J. Pasupathi
60. L. Saira*
61. Chitra M. Gokhale*
62. K. Ramesh Kumar*
63. D. Baranidharan*
64. Ganesan Radhakrishnan*
65. B.S. Srikanta*
66. P.S. Somasundaram
67. P.S. Sasikumar

Visiting Positions

1. G.S.R. Subba Rao
2. Anand Kumar (upto 23.10.'86)

Consultant Physicians

1. A.R. Pai
2. M.R. Baliga

Research Fellows

1. S. Krishna Prasad
2. R. Prathiba
3. V.N. Raja
4. V.A. Raghunathan
5. K. Usha
6. Geetha G. Nair
7. G.B.Shivkumar
8. Jyotsna Rajan*
9. Rani P. Rao

Joint Astronomy Programme

1. D. Bhattacharya
2. S. Karbelkar
3. S. Sridhar
4. Nimesh Patel
5. B. Ramesh
6. T.K. Sridharan

Resignations

1. A.C. Kunwar
2. S. Ramesha
3. U.N. Usha

\+ On leave with Cavendish Laboratory, Cambridge, U.K.

++ On leave with C.S.I.R.O. Division of Radiophysics, Sydney, Australia

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

@@ On leave with Institute for Theoretical Physics, University of California, U.S.A./Institute of Astronomy, Cambridge, U.K.

@@@ On leave with the Dowell Schlumberger, France/Carnegie-Mellon University, Pittsburgh, U.S.A.

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

*** On leave with the Institute de Radio Astronomie Millimetrique, Grenoble, France.

LIST OF VISITORS

1.	Dr. Esther Zirbel Yale University U.S.A.	June 9 - 14, 1986
2.	Dr. A.R.P. Rau Dept. of Physics and Astronomy Louisiana State University LOUISIANA, U.S.A.	July 29 - 31, 1986
3.	Dr. W.A. Coles University of San Diego California, U.S.A.	Aug. 3 - 6, 1986 Dec. 3 - 12, 1986
4.	Dr. B.G. Hooghoudt LEIDEN THE NETHERLANDS	Aug. 6 - 7, 1986
5.	Dr. M.D. Pollock Trieste ITALY	Oct. 13, 1986 - April 9, 1987
6.	Dr. J.E. Baldwin Cavendish Laboratory CAMBRIDGE UNITED KINGDOM	Oct. 23 - 26, 1986
7.	Dr. S.V. Dhurandhar Puna University PUNE INDIA	Nov. 11 - Dec. 10, 1986
8.	Dr. Arnab Rai Choudhuri National Center for Atmospheric Research High Altitude Observatory BOULDER U.S.A.	Dec. 9 - 13, 1986
9.	Dr. Sanjeev Kumar Scuola Internazionale Superiore di Studi Avanzati - International School for Advanced Studies TRIESTE, ITALY	Dec. 28, 1986 - Jan. 4, 1987

10.	Dr. Peter Shaver European Southern Observatory Munich WEST GERMANY	Dec. 30, 1986 - Jan. 3, 1987
11.	Dr. Abhay Ashtekar Syracuse University SYRACUSE U.S.A.	Jan. 2 - 7, 1987
12.	Dr. Takeshi Oka University of Chicago CHICAGO U.S.A.	Jan. 11 - 13, 1987
13.	Sir Fred Hoyle UNITED KINGDOM	Feb. 18 - 24, 1987
14.	Dr. L.P. Grishchuk Sternberg Astronomical Institute MOSCOW U.S.S.R.	March 16 - April 24, 1987

Annexure - I

PUBLICATIONS

1. The interference of polarized light as an early example of Berry's phase. (S. Ramaseshan and R. Nityananda) - Current Science, **55**, 1225 (1986).

2. Maximum Entropy Image restoration in Astronomy. (Ramesh Narayan and R. Nityananda) - Annual Reviews in Astronomy and Astrophysics, **24**, 127 (1986).

3. On the axiomatic approach to the maximum entropy principle of Inference. (S.N. Karbelkar) - Pramana, **26**, 301 (1986).

4. Ionized gas towards Galactic Centre - constraints from Low-frequency Recombination Lines. (K.R. Anantharamaiah and D. Bhattacharya) - J. Astrophysics Astr. Vol. 7, 141 (1986).

5. On the implication of the recently discovered 5 ms Binary pulsar PSR 1855+09. (D. Bhattacharya and G. Srinivasan) - Cur. Sci., **55**, 327 (1986).

6. On the White Dwarf origin of SN 1987a. (G. Srinivasan) - Cur. Sci., **56**, 245 (1987).

7. A Lagrangian basis for Ashtekar's reformulation of canonical gravity. (J. Samuel) - Pramana, **28**, L429 (1987).

8. Comment on gravitomagnetic pole and mass quantisation. (J. Samuel and B.R. Iyer) - Phys. Rev. Lett., **57**, 1089 (1986).

9. A gravitational analogue of the Dirac monopole. (J. Samuel and B.R. Iyer) - Cur. Sci., **55**,, 818 (1986).

10. Quantum Field Theory in curved spacetime: A biased overview. (B.R. Iyer) - Classical and Quantum aspects of Gravitation, eds. S. Banerji, A.K. Ray Chaudhuri, J.V. Narlikar, N. Panchapakesan and P.C. Vaidya (1987).

11. Black holes are not for ever. (B.R. Iyer) - Gurutva, April-October 1986.

12. Spacetimes with local rotational symmetry and the Dirac equation. (B.R. Iyer and C.V. Vishveshwara) - Contributed to XX International Conference on General Relativity and Gravitation, Stockholm, 1986.

13. Black hole Thermodynamics (B.R. Iyer) - Proceedings of the South Zone Winter School on General Relativity and Cosmology, Ed. A.N. Maheshwari, (1987).

14. Joint Linearization Instabilities in General Relativity. (Dieter Brill and C.V. Vishveshwara) - Journ. Math. Phys., **27**, 1813 (1986).

15. A broadband radio telescope at Gauribidanur (K.R. Subramanian, C. Nanje Gowda, A.T. Abdul Hameed and Ch.V. Sastry) - Bul. Astr. Soc. Ind., **14**, 236 (1986).

16. On the Association between supernova remnants and Pulsars. (D. Bhattacharya and G. Srinivasan) - in High Energy Phenomena Around Collapsed Stars, ed by F. Pacini, NATO ASI Series. Reidel, Dordrecht (1987).

17. The binary origin of pulsar velocities (V. Radhakrishnan and C.S. Shukre) - in High Energy Phenomena Around Collapsed Stars, ed by F. Pacini, NATO ASI Series, Reidel. Dordrecht (1987).

18. Pulsars and their genesis (V. Radhakrishnan) - Invited discourse delivered at the XIX IAU General Assembly, November 1985, New Delhi, In Highlights of Astronomy, Vol 7, ed by J.P. Swings, Reidel, Dordrecht (1986).

19. Estimation of coronal magnetic fields (N. Gopalaswamy and Ch.V. Sastry) - Bul. Astron. Inst., Czechslovakia, **37**, 115 (1986).

20. On the origin of the galactic ridge recombination lines (K.R. Anantharamaiah) - Astrophy. Astr.,**7**, 131 (1986).

21. Multipoints in liquid crystals (S. Chandrasekhar) - in Statistical Physics and Condensed Matter Theory, ed Xie Xide (World Scientific Pub. Co., 1986) p.378.

22. On the propagation of light through thin cholesteric and twisted nematic films. (S. Chandrasekhar, G.S. Ranganath and U.D. Kini) - Mol. Cryst. Liq. Cryst. Lett., **3**, 163 (1986).

23. Paramagnetic nematic liquid crystals (S. Chandrasekhar, B.K. Sadashiva, S. Ramesha and B.S. Srikanta) - Pramana **27**, L713 (1986).

24. The structure and energetics of defects in liquid crystals (S.Chandrasekhar and G.S. Ranganath) - Advances in Physics **35**, 507 (1986).

25. Density, dielectric and x-ray studies of smectic A-smectic A transitions. (B.R. Ratna, C. Nagabhushana, V.N. Raja, R. Shashidhar, S. Chandrasekhar and G. Heppke) - Mol. Cryst. Liq. Cryst., **138**, 245 (1986).

26. A Statistical thermodynamic theory of thermotropic linear main-chain polimeric liquid crystals. (R.E. Boehm, D.E. Martire and N.V. Madhusudana) - Macromolecules **19**, 2329 (1986).

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

28. High information content liquid crystal screens. (N.V. Madhusudana) - in Opto-electronic Imaging, ed. D.P. Juyal (Tata-McGraw Hill, New Delhi, 1987) p.224.

30. Universality of the reentrant nematic-smectic C-smectic A and nematic-smectic A-smectic C multiple points. (S. Somasekhara, R. Shashidhar and B.R. Ratna) - Phys. Rev. (Rapid Commn.) **A34**, 2561 (1986).

31. Coupling between nematic and smectic ordering in reentrant nematic systems. (R. Shashidhar, S. Somasekhara and B.R. Ratna) - Mol. Cryst. Liq. Cryst., **133**, 19 (1986).

32. Multicritical points in liquid crystals. (R. Shashidhar) - Physica **139** & **140B**, 609 (1986).

33. Dielectric studies of monolayer smectic A phases. (C. Nagabhushana, B.R. Ratna, G. Heppke and R. Shashidhar) - Mol. Cryst. Liq. Cryst., **139**, 209 (1986).

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