25 years of PRL

PHYSICAL RESEARCH LABORATORY AHMEDABAD INDIA

PRL research encompasses

The Earth

The Sun

immersed in the fields and radiations

reaching from and to

infinity

all that man's curiosity

and intellect

can reveal.

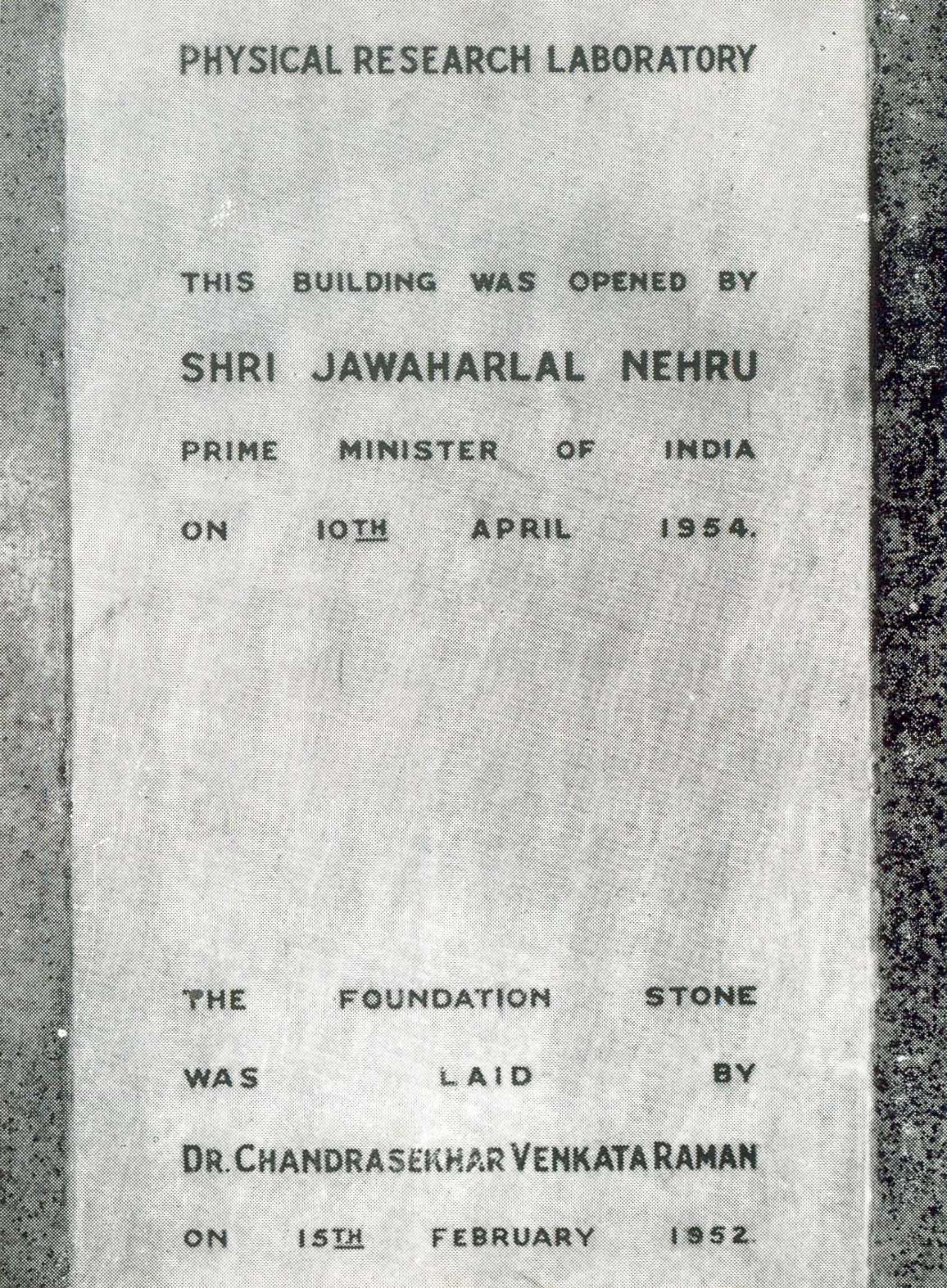
"Countries have to provide facilities for its nationals to do front rank research within the resources that are available. It is equally necessary having produced the men who can do research, to organize task-oriented projects for the nation's practical problems."

Dr. Vikram A. Sarabhai imaginative scientist and creator of PRL and many other national institutions.

Front view of PRL Building (1973)

Dr. Sarabhai's original laboratory in 'RETREAT'. Shahibaug (1947)

Dr. Sarabhai with the Prime Minister, Pandit Jawaharlal Nehru


PHYSICAL RESEARCH LABORATORY
THIS BUILDING WAS OPENED BY
SHRI JAWAHARLAL NEHRU
PRIME MINISTER OF INDIA
ON 10TH APRIL 1954.
THE FOUNDATION STONE
WAS LAID BY
DR. CHANDRASEKHAR VENKATA RAMAN
ON 15TH FEBRUARY 1952.

Preface

This brochure contains a brief account of the principal areas of research the Physical Research Laboratory (PRL) is engaged in, and of its growth to its present size.

The present attempt to describe the research activities of PRL coincides in time with a milestone in the history of the Laboratory. At the recommendation of Dr. Vikram A. Sarabhai, the Laboratory was founded following an agreement between the Ahmedabad Education Society and the Karmakshetra Educational Foundation in November 1947. The PRL has completed 25 years of existence in November 1972. The Council of Management of the PRL decided that the period November 1972 through November 1973 be celebrated as the Silver Jubilee year. A series of scientific seminars and meetings have been held at PRL to commemorate its active life for a quarter of a century as an organisation devoted to research in space and earth sciences.

The laboratory had its humble beginnings in a few rooms in the M. G. Science Institute at Ahmedabad. Dr. K. R. Ramanathan was the first Director of PRL. The early programmes of the laboratory concerned the study of a few well defined fundamental problems in space and earth sciences. These studies related to the extraterrestrial radiations received from outer space, the geophysical consequences of this bombardment and the physical and chemical properties of the upper atmosphere. These programmes resulted from the deep and personal involvement and interests of Dr. Ramanathan and Dr. Sarabhai in these areas. Subsequently the laboratory grew in an organic fashion with, of course, some trimmings, growth and modifications. Even today the basic problems studied centre around those which were undertaken twenty five years ago. However, the current approach is more versatile, more diverse, and multi-pronged. The principal areas chosen turned out to be the most exciting; the work led to discovery of new terrestrial and extraterrestrial phenomena. Thus the members of the laboratory have participated in a number of delightful adventures in the scientific arena, contributed to new gains and rapid growth in our knowledge of nature.

The intellectually rich past of the laboratory owes its being, on the one hand to the vision and scientific contributions of Dr. V. A. Sarabhai and Dr. K. R. Ramanathan, and on the other, to a number of PRL scientists who grew with the laboratory and worked in it with great devotion and untiring spirit.

Dr. Ramanathan and Dr. Sarabhai shouldered the responsibility of guiding the laboratory both as scientists and administrators. Dr. Sarabhai became the second Director of PRL in 1965 after the retirement of Dr. K. R. Ramanathan. After the sad demise of Dr. Sarabhai in December 1971, Professor M.G.K. Menon, Director, Tata Institute of Fundamental Research and Chairman, Department of Electronics Commission, served as the interim director of the laboratory for about a year.

The laboratory was also most fortunate in receiving active financial and moral support from a number of government and private bodies. The laboratory received official recognition of the Atomic Energy Commission of the Government of India, and in accordance with the quadripartite agreement of February 5, 1963, received grants from the Government of India through the Department of Atomic Energy, from the Government of Gujarat, from the Ahmedabad Education Society and from the Karmakshetra Educational Foundation. In November 1972, with the setting up of the Department of Space of the Government of India, it has been funding the laboratory instead of the Department of Atomic Energy.

The present physical size and scientific stature of the laboratory is due to the fullest support from several individuals and organisations. The laboratory would like to take this opportunity to place on record its gratitude to the late Dr. Homi Jehangir Bhabha and to Mr. H. N. Sethna and to many officers of the Department of Atomic Energy for their taking a close interest in its development; to the Government of Gujarat and its nominees who served on the PRL's Council of Management; to the Ahmedabad Education Society, and in particular to Shri Kasturbhai Lalbhai who has given the laboratory a helping and guiding hand since its inception; to the Karmakshetra Educational Foundation of Ahmedabad and its representatives for continued encouragement and support; to the late Professor Sir C. V. Raman; and to Professors S. Dhawan and M.G.K. Menon for the continued responsibilities shouldered by them in ensuring the functioning and well being of the laboratory.

The laboratory suffered a severe jolt and an irreparable loss in the death on 30th December 1971 of its founder, Vikram Sarabhai. It is indeed our great misfortune that the man who founded this laboratory, and led it to its present laudable stature in the world of science is no longer with us to either see the fruits of his selfless efforts over a quarter of a century or to shape its future destiny.

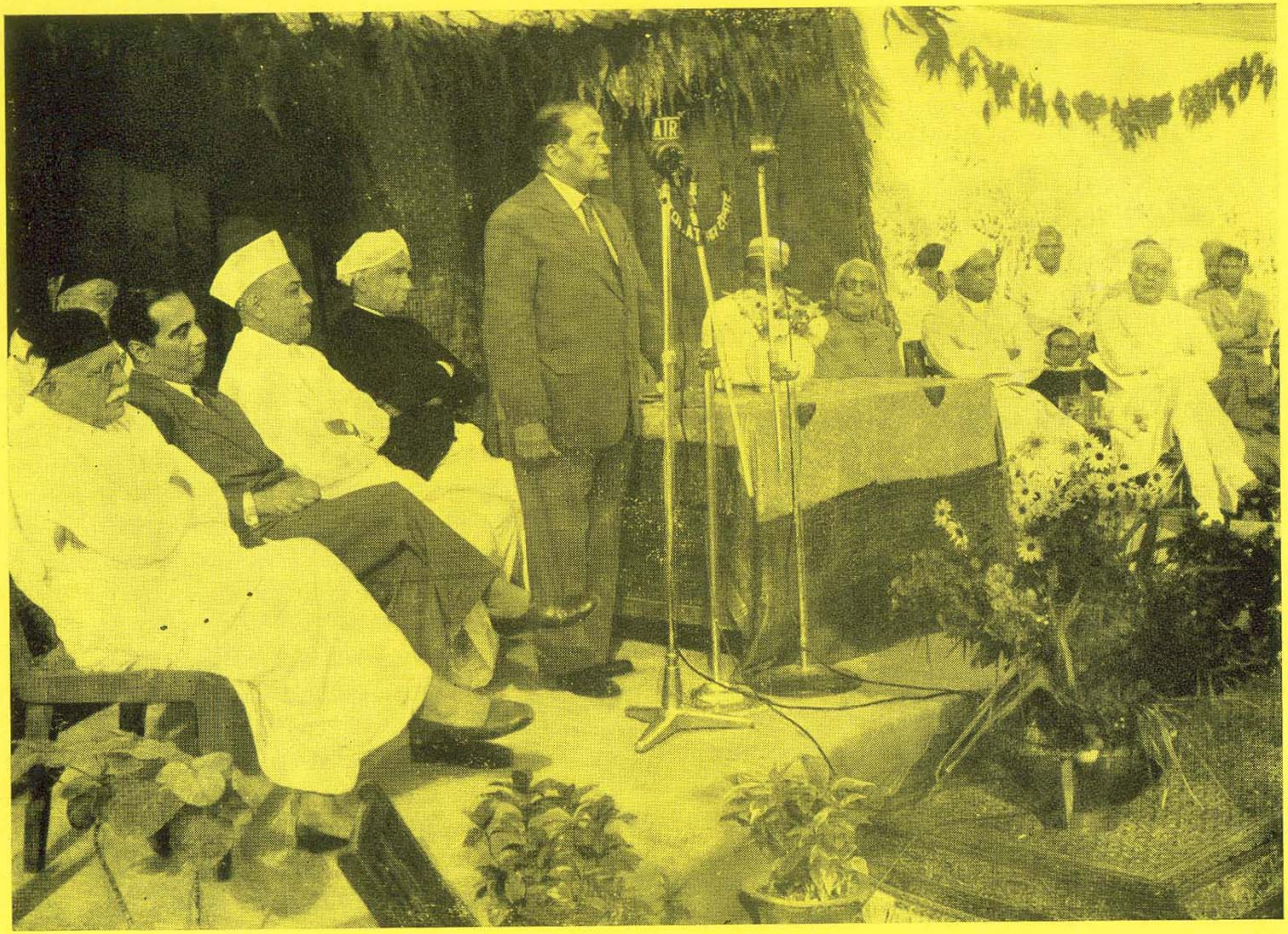
As we, the members of the Physical Research Laboratory, celebrate the Silver Jubilee of the PRL, we pay our homage to its founder and vow a dedication to an eternal pursuit of knowledge.

The PRL has so far primarily concerned itself with fundamental research in the areas of space sciences and certain special aspects of earth sciences dealing with the upper atmosphere and geomagnetism. It has, however, from time to time, engaged itself in applied research problems relevant to the country's needs, particularly in the field of electronics. There also exists a strong interaction with the neighbouring educational institutions. At the various Universities in Gujarat some of the advanced courses in physics have been taught from time to time by members of the PRL. These extra-curricular aspects of PRL are considered essential to its development, and we believe that a strong tangible interaction between PRL and the country's educational institutions should be an important facet of our activities, which are otherwise largely devoted to pure research.

The PRL has already played an important role in the country's space research activities by supplying well trained scientific personnel and by participating in the relevant crucial space experiments. A much stronger interaction is expected in the coming years, particularly with the setting up of a major space applications research program at Ahmedabad. The laboratory is now also deeply involved in applications of nuclear techniques to problems of man and society. One of these programmes concerns archaeology. The Radiocarbon Dating Laboratory at PRL is run as a national facility for archaeological studies. The other program concerns development of new methods for the study of hydrology and applications of these techniques. These programmes have recently moved over to PRL from the Tata Institute of Fundamental Research at Bombay.

The discussion of future outlook of the laboratory is best done on the basis of an assessment of the present interests, and the general expertise of the men of science at PRL. The laboratory will intensify research in the fields of plasma physics and nuclear geophysics and cosmophysics. With the existing programmes in the fields of aeronomy, cosmic rays, radioastronomy and theoretical physics it will then be possible to make a concerted multiprong attack to understand the evolutionary history of planets and their atmosphere, the geophysical consequences of radiation received by the earth, the physical and chemical structure of the earth's upper atmosphere, the magnetic field and the water cycle on the earth. Work in the nationally relevant programmes in the fields of archaeology and hydrology will be intensified. The laboratory will thus be concerned primarily with research, both fundamental and applied, in the broad areas of space and earth sciences, and certain anthropocentric issues which are nationally relevant. We hope the laboratory will continue to contribute to the great advancements our country has to make.

D. LAL
Director



Sir S. S. Bhatnagar speaking at the Foundation Stone Laying Ceremony of PRL on 15th Feb. 1952

The Laboratory

Beginnings and Growth

The Physical Research Laboratory, Ahmedabad owes its existence to Dr. Vikram A. Sarabhai and his deep interest in scientific research, his initiative, and his outstanding powers of organisation and management.

Vikram had his early education in the private school in Retreat which was organized by his parents Shri Ambalal Sarabhai and Smt. Saraladevi Sarabhai on Montessori lines. The School had imaginative teachers. A workshop formed a part of the School and Vikram loved to work there. Vikram's scientific curiosity and creative practical talent were nurtured in the Retreat School. His managerial talents were inherited from his parents.

After passing his I.Sc. with distinction from the Gujarat College, Vikram went to St. John's College, Cambridge for his higher studies in 1937, when he was 18 years old. He took his Natural Science Tripos with Physics and Mathematics in 1940 and started to do post graduate work in Nuclear Physics. Owing to the start of World War II, Vikram returned to India in 1940 and joined the Indian Institute of Science, Bangalore as a Research Scholar under Prof. C. V. Raman. Vikram chose "Cosmic Rays" as the subject of his studies. Even in 1942–43, Vikram had plans to start a Physical Research Laboratory in Ahmedabad, and when he came to Poona for some scientific discussion, he talked to Dr. Ramanathan about his tentative plans. In 1945, his parents created the "Karmakshetra Educational Foundation" for starting, carrying on, and helping to carry on advanced scientific research and educational activities of all types. In 1945 at the end of the War, Vikram returned to Cambridge and submitted in 1946 his thesis for the Ph.D. of the Cambridge University on "Cosmic Ray Investigations in Tropical Latitudes" which included his studies made at Bangalore and at Apharwat in the Kashmir region of Himalayas. Dr. Vikram was awarded his Ph.D. degree in 1947 and immediately after his return to India, set about the task of creating a P.R.L. in Ahmedabad. He had already in Retreat a Laboratory for Cosmic Rays with a skeleton staff including a Scientific Assistant knowing electronics, a glass blower and an all-round general mechanic. Knowing Dr. Ramanathan's interest in Atmospheric Physics, Geomagnetism and Solar-terrestrial relationships, Vikram sounded Dr. Ramanathan as to whether and when he would join him in establishing the Laboratory. Dr. Ramanathan agreed to join immediately after his retirement from the India Meteorological Department on 28 February 1948.

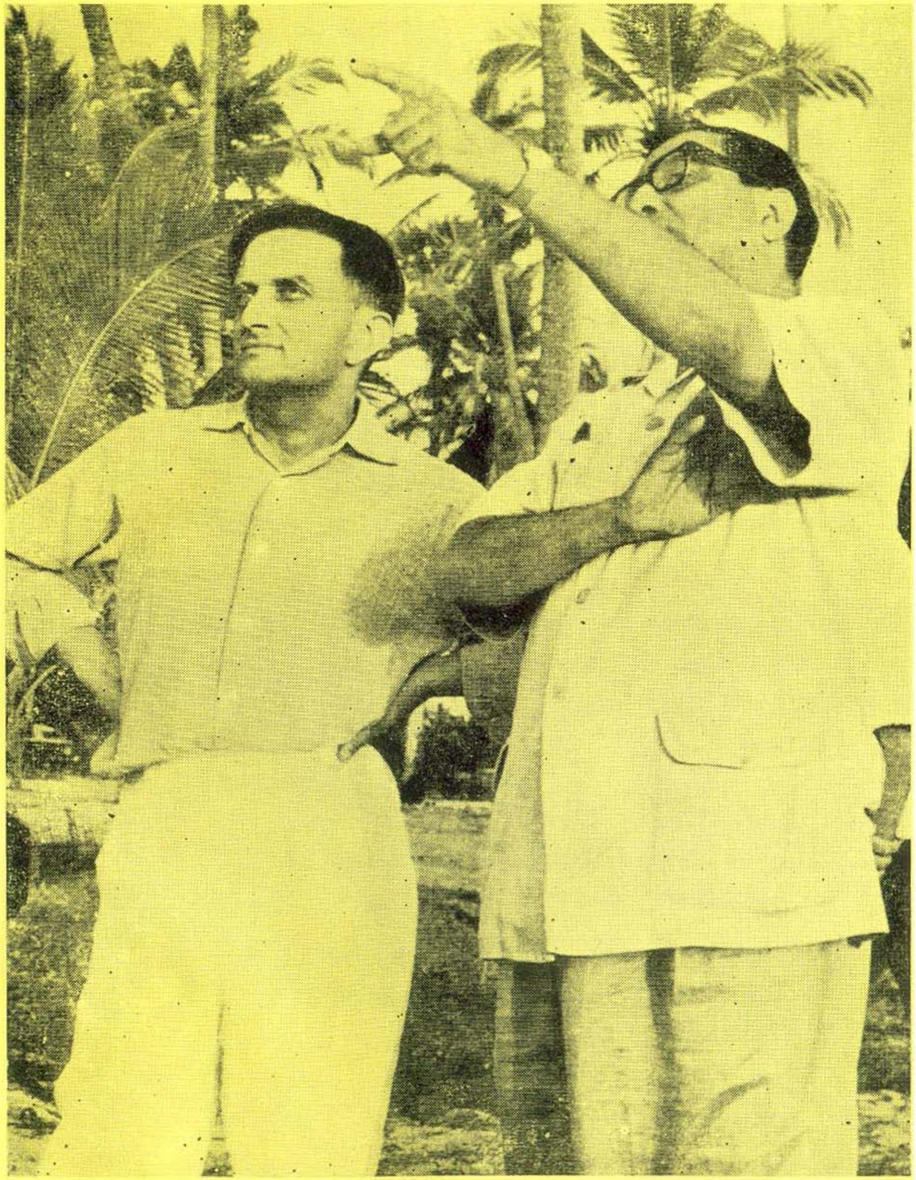
1. EARLY YEARS (1948-61)

Dr. Sarabhai also discussed with the authorities of the Ahmedabad Education Society (AES) including Shri Kasturbhai Lalbhai and Shri G. V. Mavalankar, about the possibility of collaboration between A.E.S. and K.E.F. in founding a Research Laboratory in Ahmedabad devoted to the study of Cosmic Rays and Atmospheric Physics. In November 1947, an agreement was reached between A.E.S. and K.E.F. to start a P.R.L. in Ahmedabad. The assistance of C.S.I.R. (under Sir S. S. Bhatnagar) and of the Department of Atomic Energy (under Dr. H. J. Bhabha) was also informally sought and obtained.

Pending the acquirement of suitable land and construction of appropriate buildings, the Ahmedabad Education Society provided a few rooms in the M. G. Science Institute for the work of the P.R.L., and work started there with a small laboratory and workshop, a few Research Assistants and a small office.

A few months after Dr. Ramanathan joined P.R.L. as Director and Professor of Atmospheric Physics, the Laboratory sent him out on a scientific tour to Europe to study developments in the subjects of immediate and potential interest to the Laboratory and consider the type of instruments that should be acquired for the Laboratory. He visited many scientific institutions in U.K. Ireland, Norway, Sweden, Belgium and France and made valuable scientific contacts. He also attended as an Indian delegate the meetings of the International Union of Geodesy and Geophysics in Oslo, Norway. He was elected Vice-President of the International Association of Meteorology for the period 1948-51.

The initial research programme of the Laboratory was oriented by the scientific interests of its principal workers. Professor Ramanathan was interested in the problems of temperatures, winds and moisture in the upper atmosphere, atmospheric ozone, ionospheric physics, geomagnetism and solar-terrestrial relationships. Professor Sarabhai was interested in understanding the causes of the time variation of cosmic rays and the light they could throw on the sources of cosmic rays. But it



Vikram Sarabhai with Dr. Bhabha on Velly Hill

was realised that visible light, cosmic rays and ultra-violet radiation were only some of the windows which the earth has opening on the Universe. It was known that particle radiation as well as electromagnetic radiation of other wave lengths come from outside sources and strike the earth. Radio Astronomy had revealed new and fascinating views of the Universe. After careful consideration, it was decided that the over-all programme of the Laboratory should be the integrated study of the different kinds of radiation which are received on the earth, and of their geophysical consequences. In order to carry out such a programme satisfactorily, it was felt necessary to provide for studies in Theoretical Physics and for the development of Electronics. A request was made to the Atomic Energy Commission for necessary financial assistance, and after due consideration, the request was agreed to in 1949.

In 1950, a Council of Management for the Physical Research Laboratory was formed with representatives from the Ahmedabad Education Society, the Karmakshetra Educational Foundation, the Ministry of Natural Resources and the Scientific Research, the Atomic Energy Commission of the Government of India, and the Government of Bombay. Members of the First Council of Management were :

Shri Kasturbhai Lalbhai, Chairman. Representative of the A.E.S.

Dr. S. S. Bhatnagar, F.R.S. Director, Council of Scientific and Industrial Research, India. Representative of Government of India and the Atomic Energy Commission.

Dr. K. S. Krishnan, F.R.S. Director, National Physical Laboratory. Representative of the Ahmedabad Education Society.

Prof. Y. G. Naik, Ph.D. Gujarat College, Ahmedabad. Representative of the Government of Bombay.

Prof. Vikram A. Sarabhai, Ph.D. Physical Research Laboratory. Representative of the Karmakshetra Education Foundation.

Prof. K. R. Ramanathan, D.Sc. Director, Physical Research Laboratory. Ex-officio.

Land for buildings and structures for field experiments was provided by the Ahmedabad Education Society and the foundation stone of the laboratory was laid by Professor C. V. Raman on 15 February 1952. The first building on the campus was opened by the Prime Minister Pandit Jawaharlal Nehru on 10 April 1954.

Dr. Ramanathan was elected President of the International Association of Meteorology for the period 1951–54 and later, President of the International Union of Geodesy and Geophysics in 1954–57. In 1953–54, plans for the International Geophysical Year (IGY) crystalized, and both Dr. Sarabhai and Dr. Ramanathan actively participated in drawing up programmes of work in the various disciplines of Earth Sciences, including Geomagnetism and Cosmic Rays.

2. P. R. L. AND GROWTH OF SPACE RESEARCH IN INDIA (1961–73)

After the IGY–IGC period 1957–59, when artificial earth-satellites had become a reality, a request was made by the P.R.L. to the Department of Atomic Energy to support its growing activities in the field of Space Research. Dr. Bhabha sent a team of experts to examine the work and facilities available in the laboratory, and on receiving a favourable report from them, recommended to the Government of India that the D.A.E. may give substantial block grants to the Laboratory and that the management of the Laboratory could be taken over by a Council consisting of representatives of the Government of India, Government of Gujarat, A.E.S., K.E.F. and the Director of the Laboratory. This was accepted by all the parties, and a trust deed on behalf of the four parties was signed on February 5, 1963.

The present Council of Management of the P.R.L. consists of the following members :

Prof. S. Dhawan Prof. M. G. K. Menon Shri M. A. Vellodi	Representatives of the Government of India

Shri P. R. Chauhan : Representative of the Government of Gujarat

Shri Kasturbhai Lalbhai : Representative of the Ahmedabad Education Society

Prof. K. R. Ramanathan : Representative of the Karmakshetra Educational Foundation (Chairman)

Prof. D. Lal : Director, P.R.L.

Shri S. R. Thakore : Dy. Director, P.R.L. (Secretary)

Early in 1962, D.A.E. under its responsibility for Peaceful Uses of Outer Space, had created the Indian

National Committee for Space Research (INCOSPAR) with Dr. Sarabhai as Chairman and 11 other Scientific-members including several P.R.L. scientists. Dr. Sarabhai with his characteristic energy and with whole-hearted support from Dr. Bhabha selected Thumba, on the Arabian Sea Coast and very close to the magnetic dip equator, as the most appropriate place for an Equatorial Rocket Launching Station and within a short time, obtained the co-operation of the Kerala Government and other parties and built up all the basic facilities at Thumba. In October 1963, the administrative charge of Space activities in India was entrusted by Government to P.R.L. under the direction of Dr. Sarabhai. On the evening of 21 November 1963, the first scientific rocket went up from Thumba releasing sodium vapour and showing up the winds and turbulence above 90 km.

During this period as well as in subsequent years, Dr. Sarabhai was able to draw upon the competence and expertise developed at PRL in its various scientific programmes. PRL scientists played a major role in the management and administration of the national space programmes as well as in carrying out the space research activities. The contribution of PRL in building up the tempo of space research programmes at Thumba has been crucial.

In the early phases of development of a new field in Science and Technology, a developing nation has to depend to some extent on technical assistance from friendly developed nations. Both Dr. Bhabha and Dr. Sarabhai believed that continued dependence on foreign assistance would be frustrating and that developing countries should develop independent competence in advanced technologies and use them for solving their own problems. The P.R.L. became a Centre for developing and building scientific payloads for use in rockets, in the high flying balloons and later satellites. The THUMBA organization was expanded to develop all the techniques for launching and fabricating rockets and associated telecommunication and data processing facilities. Under the auspices of INCOSPAR, an Experimental Satellite Communication Earth Station (ESCES) was established at Ahmedabad between 1965 and 1967 with UNDP assistance and with the ultimate objective of using it as a base for educational television, broadcasting and other national services.

When Dr. Bhabha passed away in January 1966, Dr. Sarabhai became responsible both for Atomic Energy and Space Research. Space activities increased rapidly both at Ahmedabad and at Thumba. In February 1968, the Thumba Rocket Station was dedicated by the Prime Minister Smt. Indira Gandhi to UN as an International Equatorial Rocket Launching Station. In 1969 an Indian Space Research Organization (ISRO) was created under DAE to carry on national programmes of Space Research and its applications for the social and economic development of the country, and its administrative control was entrusted to Director, P.R.L.

Following Dr. Sarabhai's sad demise in December 1971, a new Department of Space was created with Professor Dhawan as Secretary and Chairman of ISRO.

Thanks to the vision, energy and talent for organization and management of Dr. Vikram Sarabhai, we have today in Ahmedabad, not only the Physical Research Laboratory, but also the sister organization of Space Applications Centre (SAC) comprising several units such as Experimental Satellite Communication Earth Station (ESCES), Satellite Instructional Television Experiment (SITE), Satellite Communications Systems Division (SCSD), Electronic Systems Division (ESD), Audio Visual Instruction Division (AVID), Microwave Division (MID) and Remote Sensing and Meteorological Applications Division (RSMD).

An outgrowth of P.R.L. activities, viz., the first Indian Scientific Satellite Project (ISSP) is now actually at work at Bangalore, the Headquarters of the Department of Space. The satellite designed and fabricated in India will carry three scientific experiments, one to measure X-rays from celestial sources (PRL), the second to measure solar neutrons and gamma rays (TIFR), and the third to measure ionospheric parameters (PRL). The satellite is expected to be launched on a 40° orbit to a height of 600 km from a USSR cosmodrome in Central Asia in the latter half of 1974 using a Russian launch vehicle.

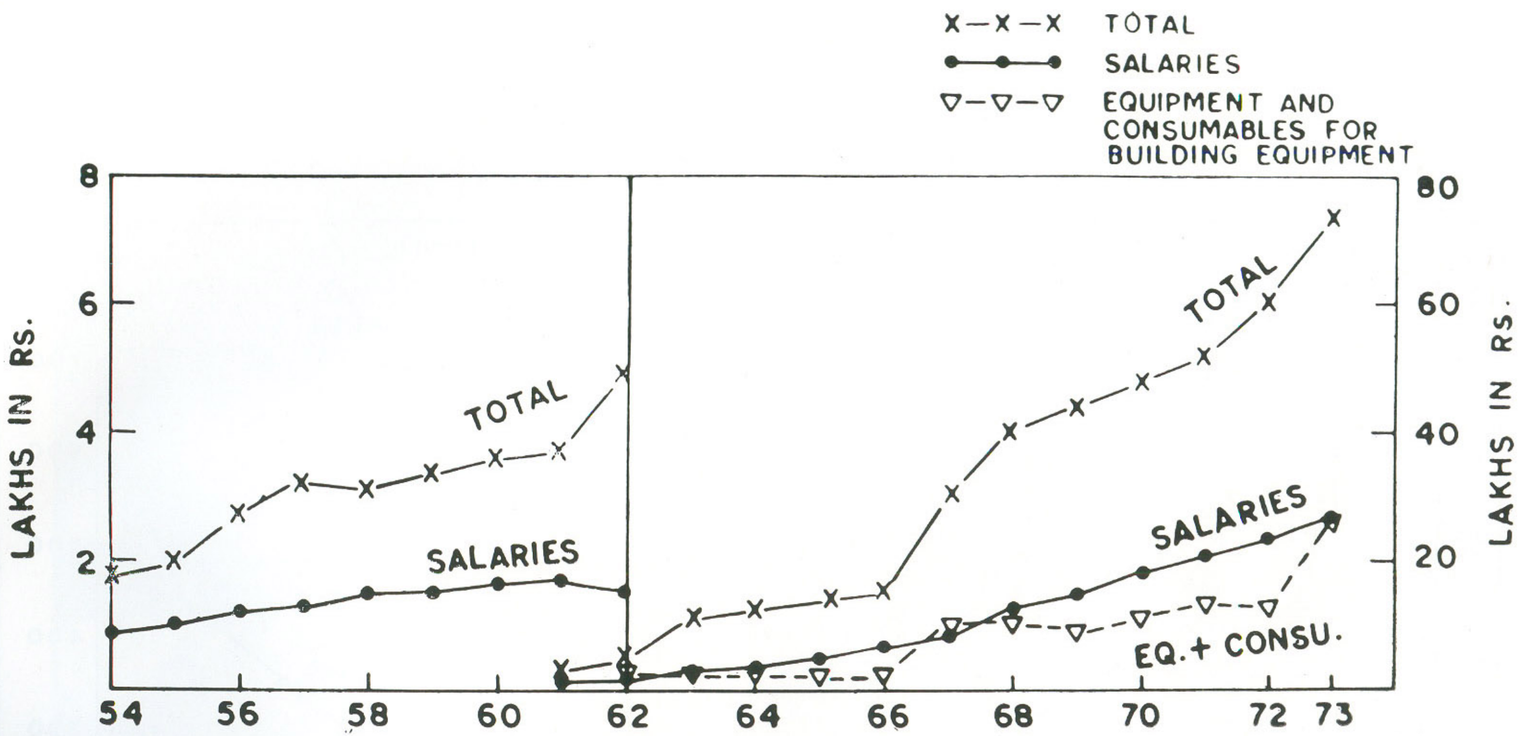
Land, Buildings and Finances

The land on which the PRL buildings and structures for experimental work are constructed is situated close to the campus of the Gujarat University. It covers an area of 51,000 square yards, and was given to the Laboratory by the Ahmedabad Education Society in 1948. The buildings on the campus grew in stages. Two floors of the First building were built in 1952–53, and a second floor was added to it in 1957–58. A second building was constructed in 1962–63 to accommodate a 1620 computer, a larger library, and two floors of research laboratories. In addition, extensions were made to provide larger space for workshop and stores.

Increased involvement of the Laboratory in Space Research and rocket instrumentation required more accommodation. The construction of a multi-storeyed building was started in 1966 on the north side of the First building enclosing a large quadrangle. By March, 1972, three floors of this building were completed. Further work has been started in 1973 to add five floors to this building. The total cost of the buildings in the PRL campus till March, 73 was about 36.3 lakhs. This includes space for IBM 360/44 computer, a large library and a large canteen.

Shortly after 1962, additional land was acquired for building a guest house and a few quarters for laboratory staff. An area of 23,000 square yards was acquired in the close neighbourhood of the laboratory. At present there are 52 quarters for the scientific and technical staff of the laboratory, a guest house and a hostel which can accommodate 24 post-graduate students. The total cost of the buildings of the guest house, quarters and hostel has been about 15.5 lakhs.

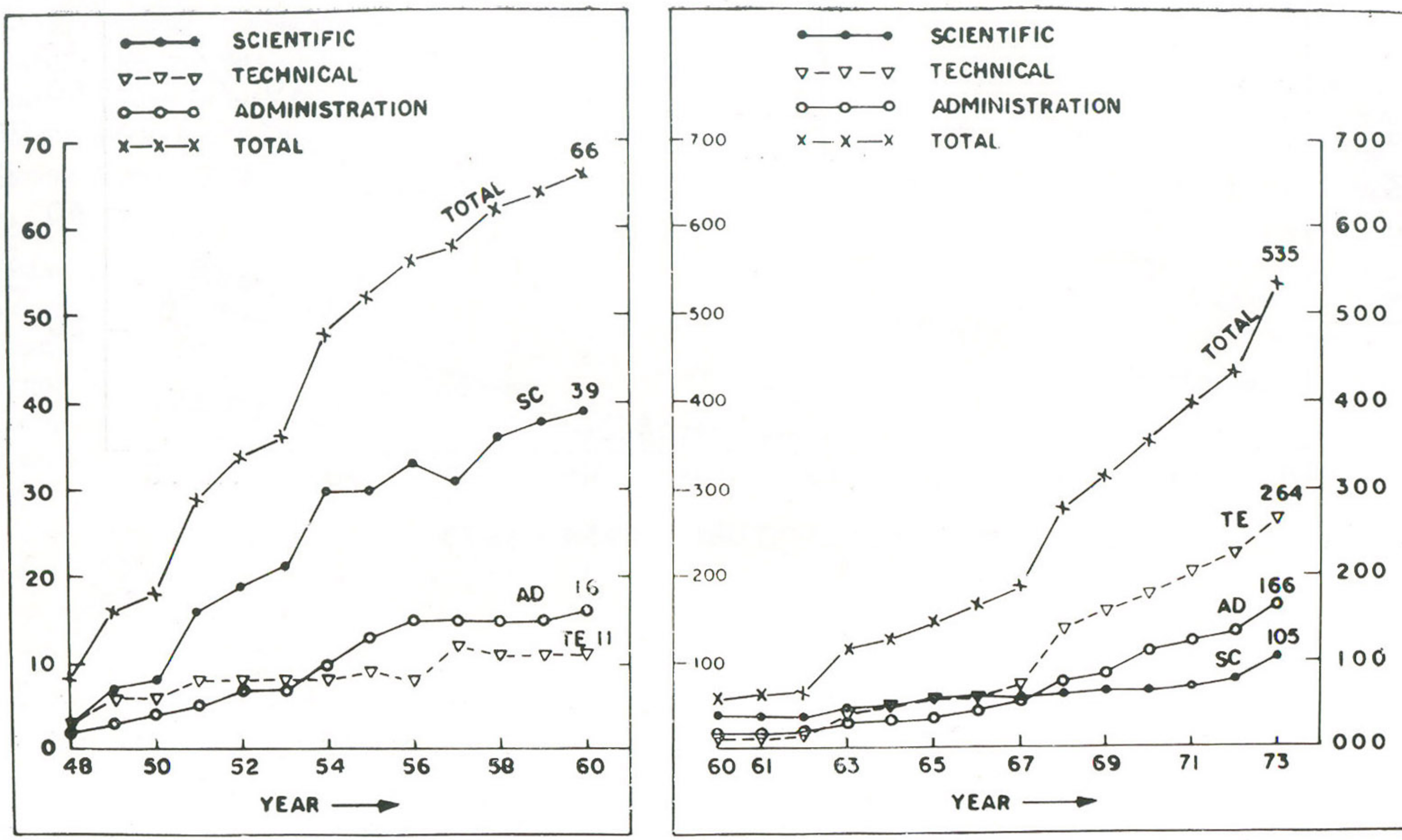
It may be mentioned that some additional land for putting up structures for work in Radio Astronomy has been provided by the Indian Space Research Organization in the ESCES campus, and land for work on absorption of radio waves in the lower ionopshere by the Gujarat University.



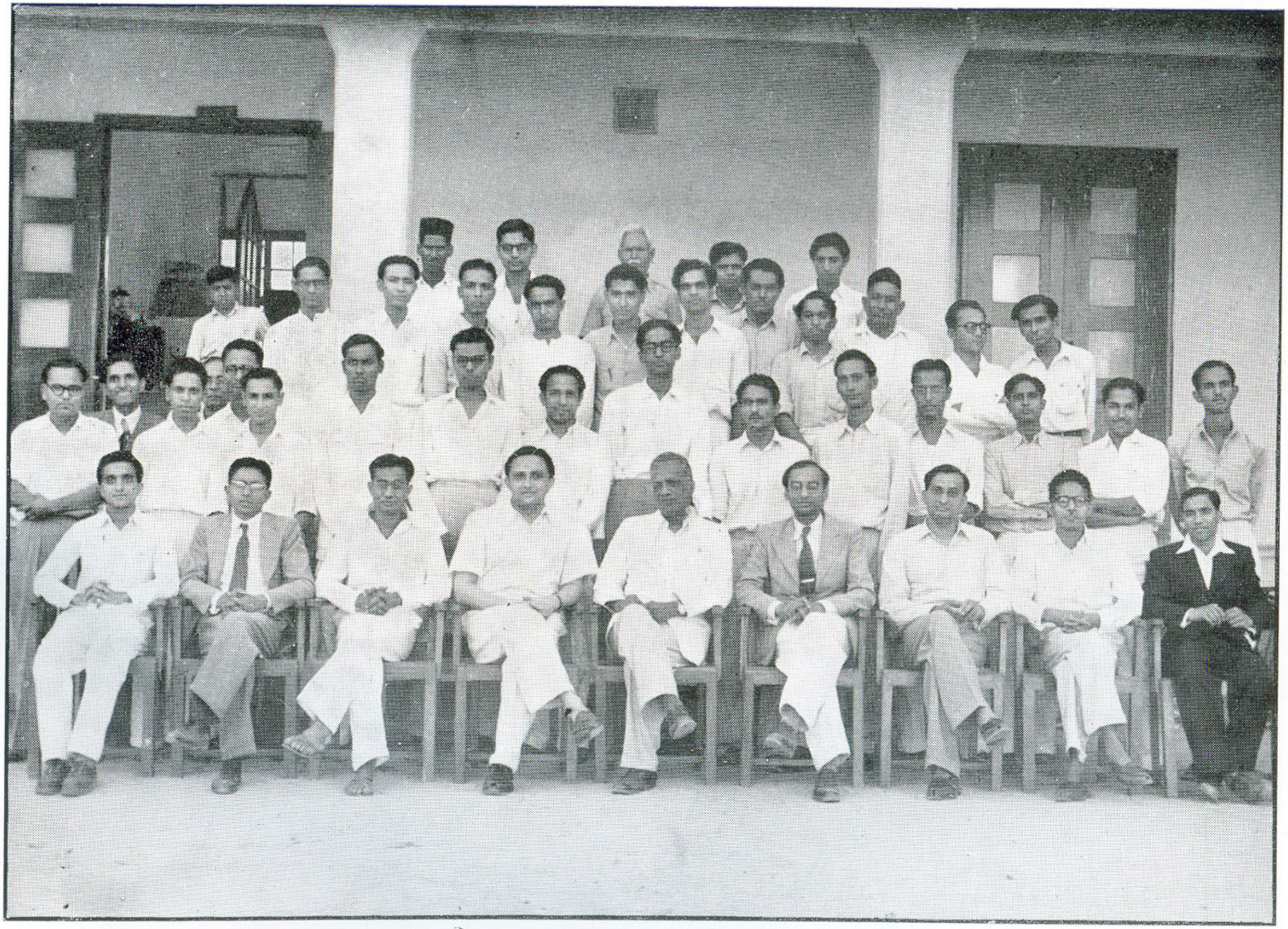
PRL EXPENDITURE 1954 - 1973

The total annual expenditure has increased

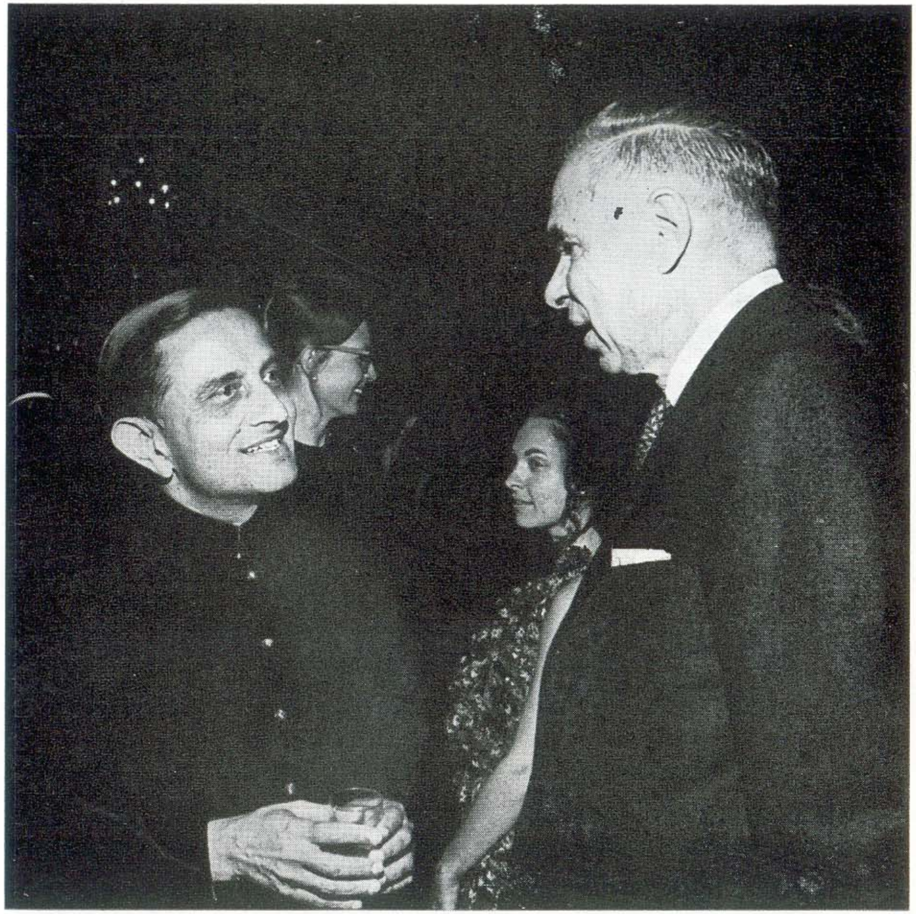
from Rs. 1.30 lakhs in 1949–50
to Rs. 2.18 lakhs in 1954–55
to Rs. 3.58 lakhs in 1959–60
to Rs. 14.44 lakhs in 1964–65
to Rs. 48.12 lakhs in 1969–70 and
to Rs. 73.53 lakhs in 1972–73



PRL STAFF 1948 - 1973



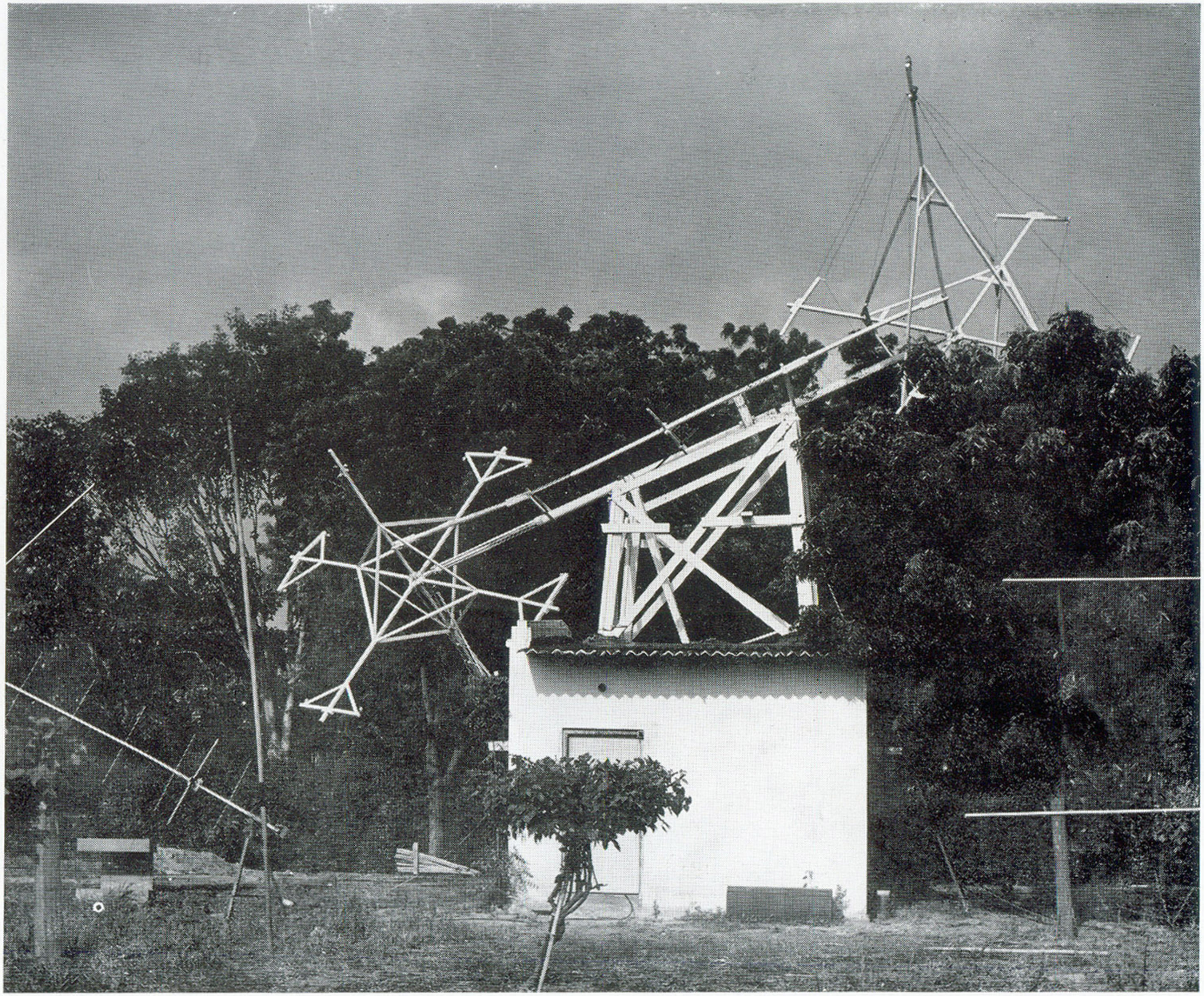
Prof. K. R. Ramanathan's 60th Birth–day (28.2.1953)



Dr. Sarabhai speaking to Dr. Seaborg, Nobel Laureate and Chairman of the Atomic Energy Commission, USA

Dr. Vikram Sarabhai with Dr. Kurt Waldheim, Secretary General of UN and Mrs. Waldheim

Scientific Activities



Antenna for Solar Radio Spectrometer

Cosmic Rays, Interplanetary Space, Astronomy

COSMIC RAYS

Well before the beginnings of the PRL, Dr. Vikram Sarabhai had made studies of the time variations of cosmic rays at Bangalore and at the high altitude station Apharwat in Kashmir. He had found a small diurnal and semi-diurnal variation of a fraction of a percent in the cosmic ray intensity as measured on the ground and as averaged over many days. The question was, how much of it represented changes in the primary cosmic rays, and how much was due to their passage through the atmosphere. One of the first objectives of the new laboratory was to prepare reliable Geiger–Muller counters and accessory electronic counting systems to record continuously the day–to–day and hour–to–hour variations of cosmic ray intensity. It was also necessary to make precise measurements of the intensities of rays coming from different directions. An automatic meson telescope with sequencers and photographic recorders was developed and brought into operation between the years 1948 and 1951.

As it was known that part of the daily variations of cosmic rays at ground level was due to changes in atmospheric pressure and in the distribution of density in the upper atmosphere, a ground meteorological station was set up, and arrangements were made for the sounding of the atmosphere over Ahmedabad with radiosondes. It was found that even after allowing for the meteorological effects of the lower atmosphere, there remained substantial day–to–day changes which had to be ascribed to extra–terrestrial causes.

A study of the recordings of Cosmic Ray intensities at the Carnegie Institute of Washington made with ionization chambers showed that besides the Forbush effect of geomagnetic storms in Cosmic Rays, there was a tendency for a 27 day recurrence of decreased amplitudes and also world–wide year–to–year changes associated with the 11 year variation in the sunspot number. It was clear that the sun had an influence on the cosmic rays received at the earth.

At a meeting of the Special Committee for the International Geophysical Year held at Brussels in 1953 from June 30 to July 3, Dr. Sarabhai made the proposal for a world–wide study of variations of cosmic ray intensity. In the proposal, he suggested specific plans and concluded :

"There is enough evidence now for us to look forward to substantial advances in our knowledge by international collaboration in investigations on the variations of cosmic ray intensity. It would be fitting if this co-operation can be achieved under the auspices of the International Council of Scientific Unions and the Committee for the Third International Geophysical Year".

The proposal was accepted. P. R. L. became an important Centre participating in global cosmic ray studies.

The outlook on Cosmic Ray studies in low latitudes in early 1954 was stated by Dr. Sarabhai as follows :

"Particles of very high energy reach the earth from all directions in space all the time. The nature of these cosmic ray particles and their energy distribution, the location of their origin and their modes of acceleration are some of the questions which the cosmic ray physicist tries to understand ....

.... "A comprehensive programme is now in progress at the Laboratory for developing an optimum technique for the study of the anisotropy of the primary radiation through the daily variation of intensity. Using narrow angle telescopes, it is hoped to gain results which would be capable of clear-cut interpretation in terms of the anisotropy of the primary radiation".

Between 1954 and 1956, a standard cubical meson telescope ($\pm$ 45° opening) with GM counters, as recommended by the IGY Committee, was developed and installed at Ahmedabad, Kodaikanal and Trivandrum. A neutron monitor was also developed and installed at these places, as well as at Gulmarg. Directional studies of meson intensities with narrow angle telescopes were made, and these revealed clearly the anisotropy of the cosmic rays.

In a review of the work done between the years 1952 and 1955, Dr. Sarabhai came to the conclusion: "We now accept the existence of large changes of primary intensity. We have good reason to believe that many of these changes represent modulations of primary intensity occurring at some distance from the earth. The changes provide a new and valuable tool to study electromagnetic fields and distribution of matter in inter-planetary and interstellar space. There appears a possibility of explaining the changes in terms of the chaotic turbulent condition of matter in such space. The changes also furnish insight into Solar Physics."

Many years ago, S. Chapman had suggested that solar corpuscular streams from solar flares or M regions would, as a result of solar rotation, take a spiral form as they approach the earth. In 1958, Parker developed the idea that even from the normal sun, there could be a continuous outflow of ionized particles guided along the magnetic lines of force which would stretch out from the sun. This "solar wind" would undergo increase in particle density and speed when a blast of plasma is ejected from an active region on the sun. A fast solar wind blowing into a weaker wind region will distort the lines of force and affect the distribution of galactic cosmic rays in the inter-planetary region and also of those received at the earth. This idea has found confirmation in the later detailed observations made by instrumented satellites.

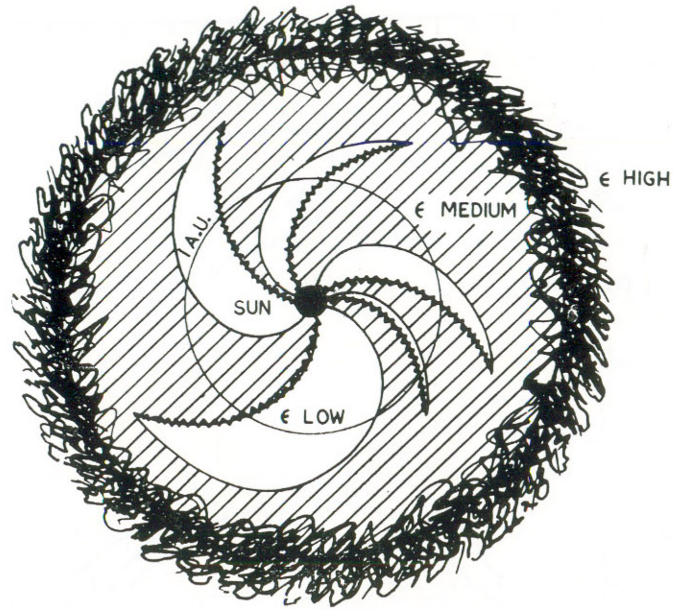
The results obtained at P.R.L. by the use of narrow angle and directional meson telescopes between the years 1953 and 1958 furnished some valuable information about the transport of cosmic rays in interplanetary space.

(1) Counter telescopes with opening angles 22° in the E–W direction and 37° in N–S, and also telescopes with angles of 15°, 5° and 2°.5 in E–W and 19° in N–S were used together with an omni-directional counter tray. While the mean time of maximum in the omni-directional instrument was near 08 hrs, it approached 12 hrs as the opening angle was reduced. The amplitude of daily variation increased from 0.3 per cent to 0.75 per cent with the decrease of opening angle.

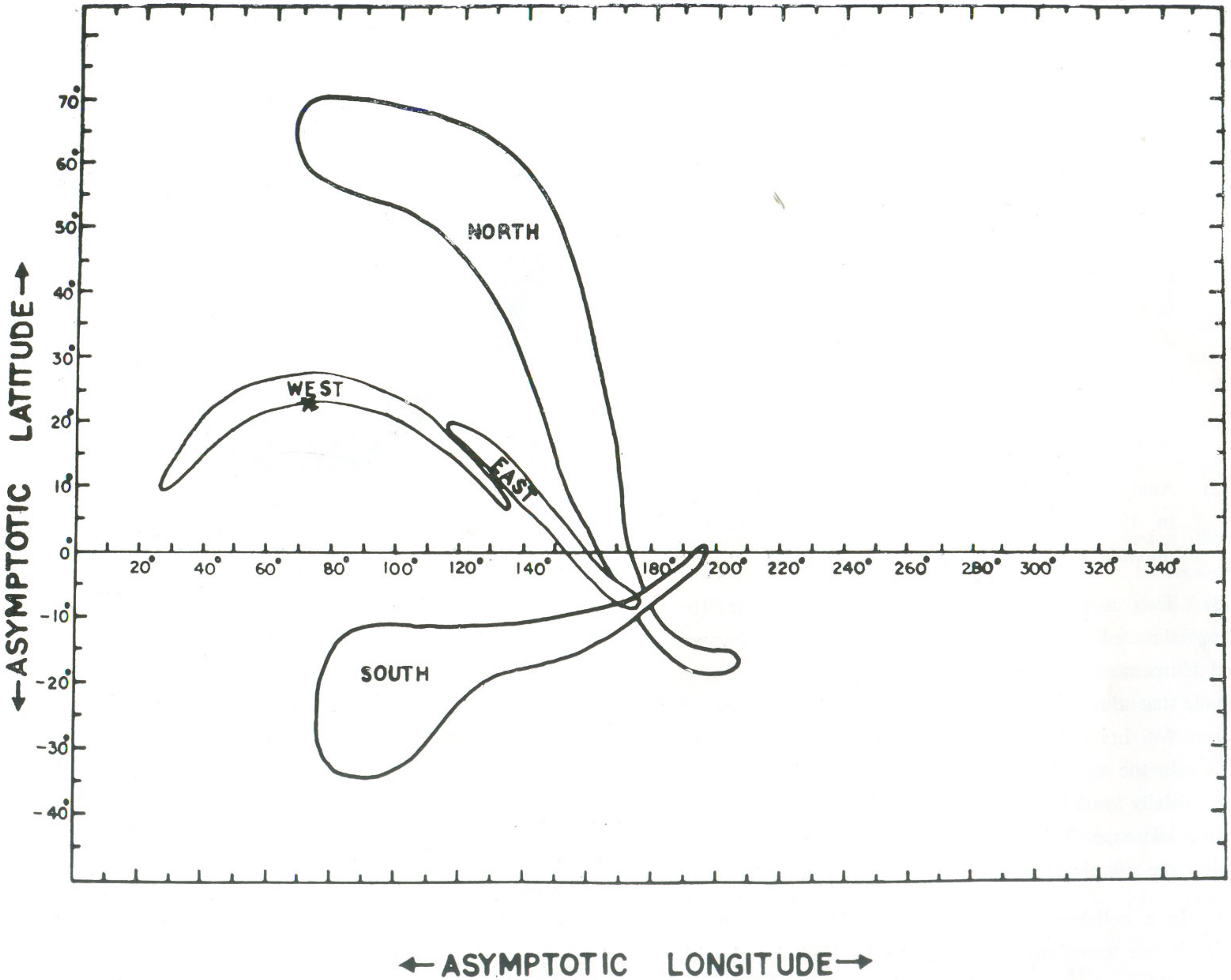
(2) Analysing the data of narrow zenith angle telescope in 1954–55, it was found that there were two maxima at about 03 hrs and 12–15 hrs.

(3) Two meson telescopes with opening angle 10° directed towards 45° East and 45° West were operated at Ahmedabad in 1957–58. It was found that the maximum in diurnal variation occurred 4–5 hrs earlier in the east-looking telescope than in the west-looking one and that the amplitude of daily variation was greater in the east-looking telescope. This proved the anisotropic character of the cosmic rays received at the earth.

In a collaborative project with M.I.T., Boston, an air shower experiment was set up in Kodaikanal with a scintillator array to study the directions of arrival of the highest energy particles. By 1957, our collaboration with M.I.T. became more intimate. A number of our post-doctorate scientists went to Chacaltaya in the Bolivian Andes, and to M.I.T., Boston to work with more elaborate equipment and became acquainted with the use of rockets and satellites for cosmic ray and Space Studies. With the installation in 1962 of an IBM 1620 Computer in PRL, analysis of large amounts of data became easier. By analysis of IGY–IGC data on a world-wide basis, it was possible to explain the diurnal and day to day variations in terms of the modulation of galactic cosmic rays of different energies by changes in the electromagnetic state of the inter-planetary medium.



Artists' model of conditions in interplanetary space around the sun when high speed solar plasma interacts with the normal lower speed solar wind



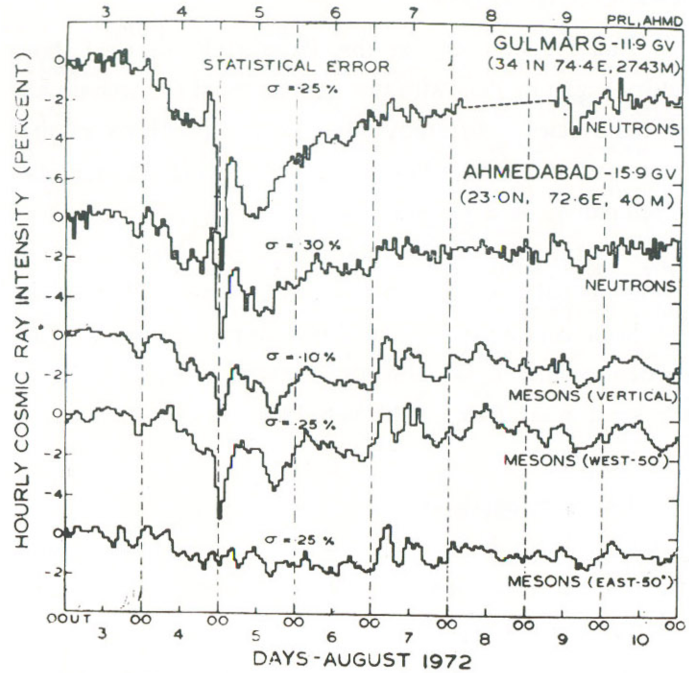
Directions in space from which cosmic ray particles reach the various inclined meson telescopes at Ahmedabad

Realising the importance of continued ground based studies for understanding the processes of modulation of galactic cosmic rays by the interplanetary medium, inclined as well as vertical high counting rate scintillator telescopes for continuous recording of mu–mesons were set up. A super–neutron monitor with a capacity of recording about a million neutrons per hour was also set up in Ahmedabad in 1968. A neutron monitor pile has also been operating at Gulmarg.

The data of the super–neutron monitor have been analysed alongwith the data from other neutron monitors in the world network, and also with the information about low energy cosmic rays of *solar origin* collected from various spacecrafts of U.S.A. The escape of solar cosmic ray particles is found to be governed by their convection by solar wind and by diffusion due to azimuthal gradients of particle density. It is concluded that the average diurnal variation vector of galactic cosmic rays can undergo variations both in amplitude and direction due to solar flares and altered solar wind and modified convection of plasma along the inter–planetary magnetic field and/or scattering and diffusion across the changing field.

Theoretical studies of Indian data together with world data of mesons and neutrons, geomagnetism and coronal emission of 5303 A° are continuing and an integrated view of both long term and short term variations of cosmic rays in terms of the properties of the interplanetary field is emerging.

Mention may be made of the study being carried out since 1966 of high energy muons (of energy



Cosmic Ray intensity changes during the great magnetic storm of August, 1972

>150GeV) associated with the TIFR extensive air shower particles in the Kolar Gold Fields at a depth of 580 metres of equivalent water, using scintillators and neon flash tubes.

The principal workers in this area of research have been Vikram Sarabhai, C. P. Joshi, U. D. Desai, R. P. Kane, P. D. Bhavsar, T. S. G. Sastry, D. Venkatesan, Ahluwalia, G. L. Pai, Satya Prakash, S. P. Duggal, H. Razdan, N. W. Nerurkar, U. R. Rao, G. Subramanian, B. Gottlieb, B. Chowdhury and their students. A list of PRL Scholars who have taken their research degrees by work in this field is given at the end of this section.

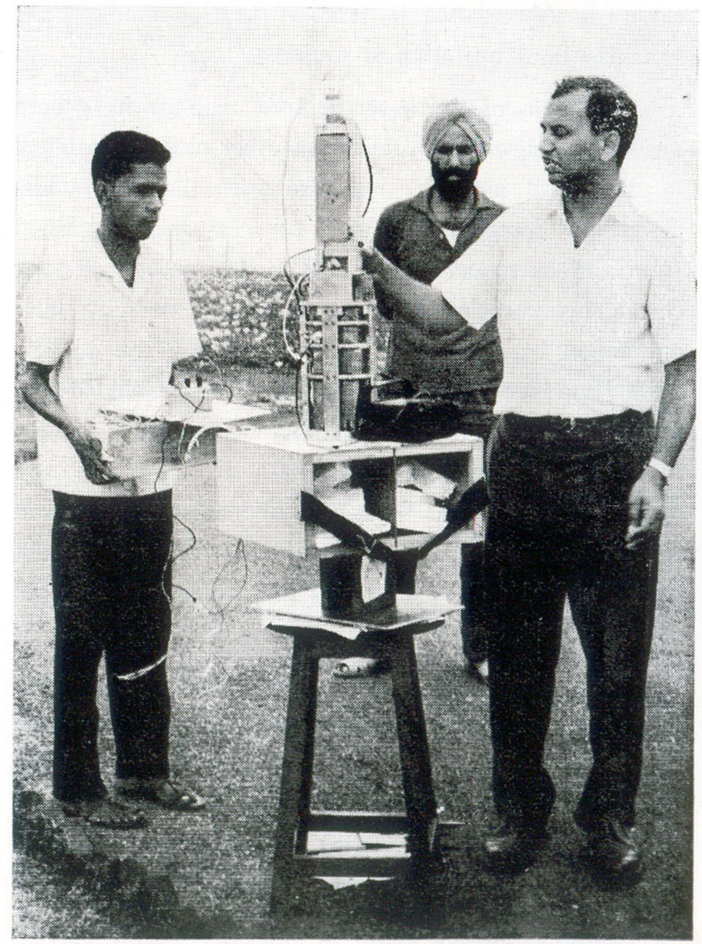
RADIO ASTRONOMY

Radio Astronomy at the Physical Research Laboratory began in 1955 with the application of the techniques of radio science to study some of the problems of the physics of the earth's high atmosphere. This required the development of a Cosmic (galactic) radio noise monitor in the form of a simple radio telescope. Regular monitering of galactic radio noise commenced in 1956 and has been continued in a modified form since then. The sudden cosmic noise absorption event associated with the great solar flare of 23 Feb 1956 was recorded with this equipment.

The next important step was taken in 1964 when a Relative Ionospheric Opacity Meter (Riometer) was constructed and installed for measuring ionospheric attenuation at 21.3 MHz.

In order to study solar burst phenomena more systematically, it was decided to set up a "solar radio spectroscope". Three swept frequency receivers and cathode ray display units were procured from Germany in consultation with Prof. K. O. Kiepenhauer. Three wide-band rhombic antennas, which were equatorially mounted and driven electrically to track the sun, were indigenously developed. The solar radio spectroscope (40–240 MHz) became fully operational in June 1967. This equipment fills a gap between the far eastern and European stations for a 24 hour patrol of solar bursts.

Since September 1970, PRL has put in operation a "Dicke-switched type" microwave solar radiometer operating at 2800 MHz. This measures with good accuracy the quiet sun component of radiation, the slowly varying component associated with centers of activity on the sun and the burst component associated with solar flares. Further, it is known that solar X-rays, which cause sudden ionospheric disturbances, are intimately related to microwave solar burst radiation and this is observable by means of the ground-based radio–



Rocket Payload for X-ray Astronomy

meter. This radiometer has recently been shifted from the PRL campus to ESCES premises for daily operation.

In order to obtain complete information on polarization characteristics of short lived solar bursts, a time sharing radio polarimeter operating at 35 MHz was put into operation in 1969. The polarimeter continuously records quantities proportional to the Stokes parameters, which completely define the state of polarization of incoming solar radiation. The aim of this experiment is to measure the depolarization caused by the Faraday dispersion due to finite receiver bandwidth. This would permit the determination of total Faraday rotation from the source in the sun's corona to the observer. It has been shown that out of a total Faraday rotation of about 1000 radians, only about 100 radians occur in the earth's ionosphere.

When a very high frequency radio wave from a radio star passes through the ionosphere, it undergoes an irregular refraction owing to the presence of irregularities in the electron density distribution in the earth's ionosphere. The radio star scintillations thus produced are best studied using two antenna Ryle-type phase-switched radio interferometers. At Ahmedabad, we have set up one such phase-switched interferometer operating at 60 MHz. At Gulmarg, we have another phase-switched interferometer operating at 74 MHz. Unlike at high and equatorial latitudes, the scintillation activity at Ahmedabad and Gulmarg is relatively moderate.

The main workers in Radio Astronomy are R. V. Bhonsle, S. Alurkar and their students.

X-RAY ASTRONOMY

Taking advantage of the minimal charged particle fluxes at equatorial latitudes due to the high geomagnetic cut-off, balloon experiments at the TIFR balloon launching station at Hyderabad and rocket experiments at Thumba, were started in 1968 for studies of X-ray sources and their emissions. The balloon-borne X-ray astronomy payload has an oriented platform from which the telescope can be made to look in pre-programmed directions. Stars like CEN-XI and CYG-1 having spectacular time variations have been studied. The diffuse background of X-rays, which is apparently isotropic has also been studied and the nature of its spectrum in the region 1-1000 KeV has been established.

Thin-window proportional counter for the detection of X-rays of low energies (below 1 KeV) as well as of electrons in the energy regime 10 KeV have been fabricated.

The X-ray Astronomy Group has designed and is constructing a celestial X-ray experiment package to be flown in the first Indian Satellite by the end of 1974. The emphasis in this experiment is on the scanning of various celestial sources with a detector sensitive at energies above 20 KeV. A second detector with its look-direction along the spin axis of the satellite and covering the energy range 2-15 KeV will make observations of a restricted region of the sky for a long duration of time. The first prototype of the experiment has been fabricated and flight-tested in a balloon.

The principal workers in this field have been Prof. U. R. Rao, Prakasa Rao and Kasturirangan, and their students.

	AUTHOR	TITLE OF THE THESIS	DEGREE (YEAR)	RESEARCH GUIDE
1.	R.P. Kane	Time variation of cosmic ray intensity near the geomagnetic equator.	Ph.D (1952)	V.A. Sarabhai
2.	P.D. Bhavsar	Day–to–day variation of the cosmic ray shower intensity at Ahmedabad.	M.Sc. (1952)	V.A. Sarabhai
3.	V.L. Parikh	Daily variation of the shower intensity of cosmic radiation at Ahmedabad.	M.Sc. (1952)	V.A. Sarabhai
4.	U.D. Desai	Studies in cosmic rays.	Ph.D (1953)	V.A. Sarabhai
5.	B.A. Desai	Transition effect at small thicknesses of lead of the star–producing radiation in cosmic rays.	M.Sc. (1953)	V.A. Sarabhai
6.	V.L. Bhatt	Transition effect at large thickness of lead of the star–producing radiation in cosmic rays.	M.Sc. (1953)	V.A. Sarabhai
7.	D. Venkatesan	Dissertation on a study of the time variation of cosmic rays at low latitudes.	Ph.D (1954)	V.A. Sarabhai
8.	Krishna Ramanathan	On the daily variation of Meson intensity at Ahmedabad.	M.Sc. (1956)	V.A. Sarabhai
9.	N.W. Nerurkar	Dissertation on the daily variation of cosmic–ray variation and intensity at Ahmedabad.	Ph.D. (1956)	V.A. Sarabhai
10.	P. D. Bhavsar	Studies in cosmic rays.	Ph.D (1957)	V.A. Sarabhai
11.	T.S.G. Sastry	Study of the time variation of cosmic–rays at low latitudes.	Ph.D (1958)	V.A. Sarabhai
12.	Satya Prakash	Study of the daily variation of locally produced neutrons.	Ph.D (1958)	V.A. Sarabhai
13.	S.P. Duggal	Studies of the time variation of cosmic rays at low latitudes.	Ph.D (1959)	V.A. Sarabhai
14.	S.R. Thakore	Time variation of cosmic ray intensity at Ahmedabad.	M.Sc. (1959)	R.P. Kane
15.	H.S. Ahluwalia	Study of time variations of cosmic rays at low and intermediate latitudes.	Ph.D (1960)	V.A. Sarabhai

	AUTHOR	TITLE OF THE THESIS	DEGREE (YEAR)	RESEARCH GUIDE
16.	U.R. Rao	Dissertation on studies in cosmic rays.	Ph.D (1960)	V.A. Sarabhai
17.	B.A. Holla	Time variation of nucleonic component of cosmic ray intensity.	M.Sc. (1960)	R.P. Kane
18.	H.L. Razdan	Studies in cosmic rays.	Ph.D (1960)	V.A. Sarabhai
19.	G.L. Pai	Study of time variation of cosmic rays at the geomagnetic equator.	Ph.D (1961)	V.A. Sarabhai
20.	B. Gottlieb	Studies in cosmic rays.	Ph.D (1963)	V.A. Sarabhai
21.	K. Ramanathan	Basic mechanism of MgO–type cold cathode emission.	Ph.D (1963)	V.A. Sarabhai
22.	G. Subramaniam	Studies in cosmic rays.	Ph.D (1964)	V.A. Sarabhai
23.	M.S. Dhanju	Studies in short period variations of cosmic ray intensity.	Ph.D (1968)	V.A. Sarabhai
24.	S.R. Kane	Time variation of cosmic ray intensity at geo–magnetic equator.	M.Sc. (1969)	R.P. Kane
25.	D.M. Patel	Studies in cosmic rays.	Ph.D (1970)	V.A. Sarabhai
26.	K. Kasturirangan	Study of cosmic rays and other ionising radia–tions at balloon altitudes.	Ph.D (1970)	U.R. Rao
27.	A.S. Prakasa Rao	Studies in cosmic rays.	Ph.D (1970)	U.R. Rao
28.	K. Narayanan Nair	Time variation of cosmic ray intensity and of geomagnetic field.	Ph.D (1971)	V.A. Sarabhai
29.	Y.C. Saxena	A study of muons associated with extensive air showers.	Ph.D (1971)	Bibha Chowdhury
30.	L.V. Kargathra	Investigation of the anisotropy of galactic cosmic rays with scintillation telescope.	Ph.D (1973)	V.A. Sarabhai
31.	K.P. Singhal	Studies of the secondary components of cosmic rays.	Ph.D (1973)	R.P. Kane
32.	U.B. Jayanthi	Studies in X–ray Astronomy.	Ph.D (1973)	U.R. Rao
33.	S.P. Agrawal	Study of cosmic–ray variations.	Ph.D (1973)	U.R. Rao

Aeronomy and Geomagnetism

The programme of work in AERONOMY at the P.R.L. was initiated on the consideration that INDIA occupies a large region coming under the influence of the most important monsoon system of the world, and that the magnetic dip equator passes through the extreme south of the country. Previous work had shown that there were important differences in the conducting properties of the ionosphere as we go from the equator to the pole, and as we go round the earth from India through Africa and Europe to America and the Pacific, and that these have to be properly understood for the effective utilisation of the atmosphere for communication and broadcasting. It was felt that further critical studies of the behaviour of the upper atmosphere over India and their comparison with similar studies elsewhere would make an important contribution to global aeronomy, geomagnetism, and researches on solar and extra-terrestrial radiations which cause spatial and temporal changes in the earth's environment.

Work started in 1948–49 with observations of atmospheric ozone and its vertical distribution using a Dobson Spectrophotometer, the setting up of a surface meteorological observatory and upper air observations of pressures, temperature, humidities, and winds in the meteorological part of the atmosphere. Optical measurements of the properties of the atmosphere were also started using photo–electric photometry of the sky during twilight. Finding that the atmosphere over Ahmedabad was often contaminated with varying amounts of smoke and haze, the optical observations were shifted to Mt. Abu in 1951.

Simultaneously, an ionospheric sounding equipment was installed on the campus of the P.R.L. and regular observations started in January 1953. It is interesting to note that at about the same time, a new ionosonde station was started by the India Meteorological Department at the Solar Physics Observatory, Kodaikanal situated within 1° of the magnetic equator.

ATMOSPHERIC OZONE

The Laboratory has used Dobson Spectrophotometers to make continuous observations of total ozone in the atmosphere at Ahmedabad or Mt. Abu and at Gulmarg or Srinagar. The vertical distribution of ozone was determined at a number of stations in India extending from Kodaikanal in the south to Srinagar in the north using the Umkehr method. The work started when Dr. Ramanathan was in the India Meteorological Department and collaboration with that Department has continued.

The problems of atmospheric ozone on which useful work has been done can be summarised as follows :

Prof. K. R. Ramanathan

(1) The latitudinal and seasonal variations of total ozone and their relation to weather. The difference between the stratospheric circulations of the northern and southern hemispheres as revealed by the seasonal variations in ozone amount in the two hemispheres.

(2) The nocturnal increase in ozone amount.

(3) The accuracy of the absorption coefficients of ozone used in determining the ozone amounts with the Dobson Spectrophotometers and the effect of large–particle scattering in the atmosphere on the attenuation of light of different wave–length passing through the atmosphere.

(4) The vertical distribution of ozone at different places as determined by the Umkehr method and their interpretation in terms of stratospheric transport, global distribution, and stratosphere–troposphere coupling.

(5) The quasi–biennial variation of ozone and its connection with the quasi–biennial variation of equatorial stratospheric winds.

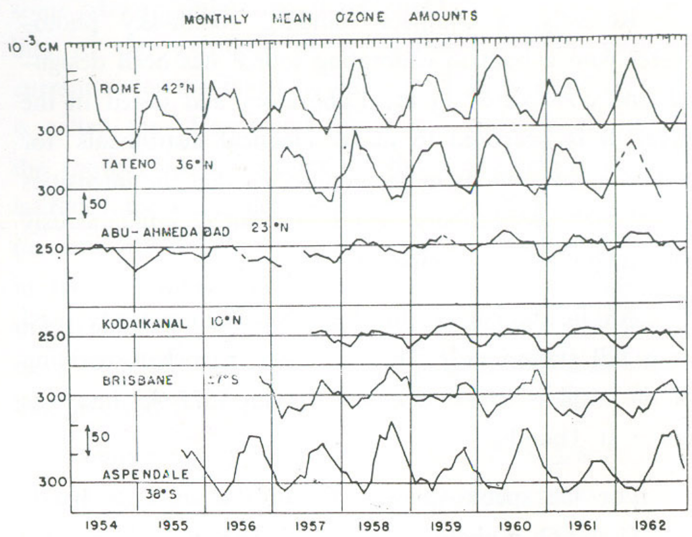
(6) The discovery of a second Umkehr and its explanation as due to scattering by stratospheric aerosols at varying heights between 20 and 28 km.

In the ozone and aerosol studies of the Physical Research Laboratory, R. V. Karandikar, Bh. V. Ramana Murthy, S. V. Venkateswaran, R. N. Kulkarni, J. V. Dave, S. S. Degaonkar, G. M. Shah and P. D. Angreji have actively worked with Professor Ramanathan over a long period of years. Prof. Ramanathan became President of the International Ozone Commission in 1960 and continued in that capacity till 1967.

WINDS AND TEMPERATURES IN THE EQUATORIAL STRATOSPHERE AND MESOSPHERE

For measuring winds in the upper atmosphere, we have to depend either on ground–based observations of identifiable objects such as balloons, or on natural phenomena like clouds. At higher levels, we can make use of suitable material such as chaff or parachutes released from rockets. During the IQSY in 1964, the P.R.L. in collaboration with the Institute of Tropical Meteorology arranged for releases of chaff from Judi rockets launched from Thumba and for following its movement with a micro–wave radar. The rockets themselves were obtained from U.S.A. under a UNDP scheme. The wind and turbulence results obtained during the year 1964 to 1966 up to an altitude of 65 km have been discussed by M.S.V. Rao of the India Met. Department. In March 1970, in collaboration with the British Met. Office, 10 Skua rockets were launched from TERLS with equipment for measuring temperatures and winds up to 60 km. Since December 1970 under a collaborative programme with the Hydro–meteorological Service of U.S.S.R., M–100 rockets are being launched from Thumba every Wednesday. Temperature data up to 55 km and wind data up to 80 km have been obtained in different months of the year. Between Decembr 1970 and March 1973, 119 M–100 rockets have been launched.

A suitable temperature measuring equipment has been fabricated at PRL, to be carried in India–made Menaka II rockets which are now in production at the Vikram Sarabhai Space Centre, Thumba.



Biennial variation of ozone

TWILIGHT GLOW

Photo–electric photometry of twilight glow was started in 1949–50. The necessary equipment was made and tested at Ahmedabad and the observations taken at Abu. Detailed calculations were made of the secondary scattering of sunlight by the molecules of the atmosphere in different wave–lengths. The effect of aerosols in the stratosphere on the intensity and polarisation of skylight at different depressions of the sun below the horizon was elucidated.

Besides ozone, there are a number of trace constituents in the stratosphere and mesosphere with specific properties as regards absorption and emission of radiation, photochemistry and chemical reactivity. The quantitative evaluation of their global distribution and changes with time present problems of varying degrees of difficulty. Examples of such trace constituents are excited molecules of oxygen $O_2(^1\Delta_g)$ and $O_2(^3\Sigma^+)$, OH, NO, water cluster ions etc. They affect twilight glow and night airglow.

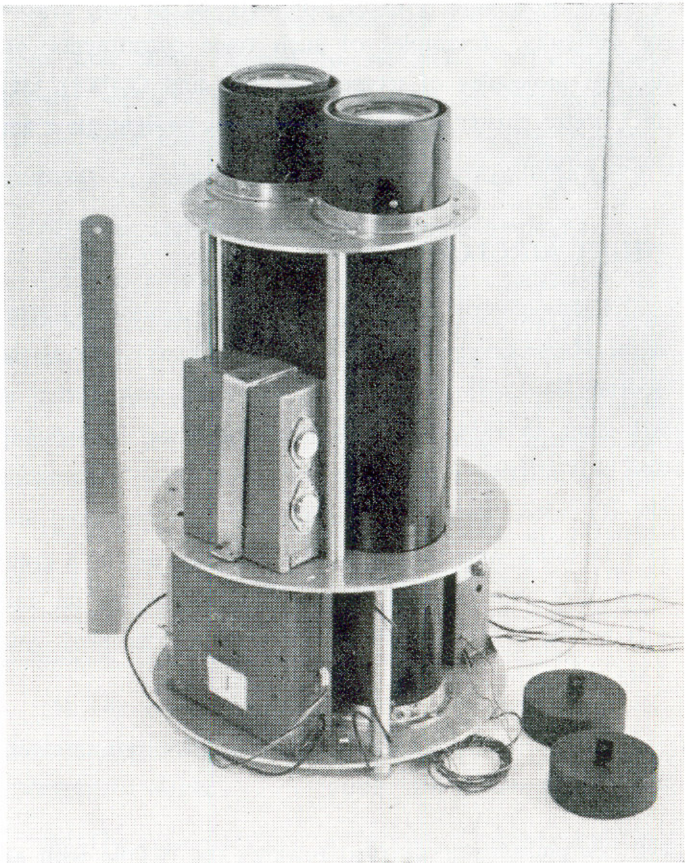
NIGHT AIRGLOW

Photo–electric photometry of airglow emissions during night of the Oxygen lines 5577 and 6300 A° and of the sodium line 5893 A° from the night sky was started at Mt. Abu in 1956 with equipment built at Ahmedabad and was carried out during the years 1956–59 covering the IGY–IGC period. The equipment was improved and new facilities were added in 1964 with the aid of a grant from U.S. Air Force Laboratory. Observations on two OH bands, (7–2) and (8–3), at wave–lengths 6862 and 7245 A° were added.

The following recording photo–electric photometers are now in use at Mt. Abu :

(1) A photometer directed towards the N.Pole with an angular aperture of 7° .5 and monitoring 5577, 6800 and 5893 A°.

(2) A zenith sky photometer for the above emissions and for OH(7–2) and (8–3) bands. An additional filter at 6080 A° to measure the varying continuum radiation from the variable star and sky background and a C–14 phosphorescent screen (standardised at the Boulder Laboratories of U.S.A.) have been added for calibrating the emissions.



Rocket Payload for Night–airglow (5577A°) flown from THUMBA on 2nd Feb. 1973

(3) An all–sky scanning photometer mounted on an altazimuth frame capable of making measurements of night glow emissions at all azimuths and at different vertical angles in quick succession. Narrow band interference filters centred at 5577, 6300 and 5890 A° are used.

Recently, a compact standard zenith–sky photometer with a built–in calibrating source has been designed and constructed in the Laboratory and tested in the field. It is proposed to make identical instruments for use at a few stations in the country so that the intensities of the night sky emissions can be measured simultaneously and quantitatively compared.

An instrument of this kind has been recently used at a hill station near Thumba when a rocket sounding of the airglow emission of the oxygen 5577 A° line was made at Thumba.

For the spectro–photometry of the emission bands of OH and O_2 a photo–electric grating spectro–photometer of the Ebert–Fastic type has been constructed and is under test.

Our twilight glow and night airglow work has contributed significantly to the knowledge of tropical night airglow. The diurnal, seasonal and latitudinal variations of airglow intensity and their connection with ionospheric parameters have been elucidated. An interesting effect of radiations from the X–ray star TAU(X–1) on the airglow intensity of OH emission has been discovered.

The main workers in this group have been P. V. Kulkarni and his students.

IONOSPHERE STUDIES WITH GROUND–BASED EQUIPMENT

Ground–based observations of the daily variation of the earth's magnetic field at and near the magnetic equator in India, Africa and S. America had shown some abnormalities and these could be explained as if due to the existence of a narrow band of electric currents over the magnetic equator. This band of current is called the "Equatorial Electrojet". Critical studies of the morphological features of the ionosphere over low latitudes including the electrojet, their relation to geo-magnetism and influx of solar radiation at different levels in the atmosphere, and comparison of data collected in this region with related data in other parts of the world have been the objectives of research in this area. This has involved the following activities :

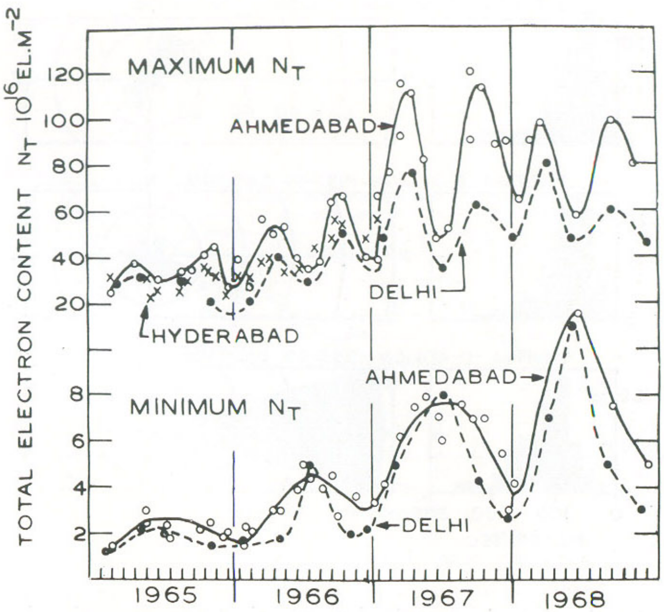
(1) Setting up of an ionosonde station at Ahmedabad (1950–52) and of another at Thumba (1964); maintenance of these stations and analysis and study of the records.

Through this activity, various features of the E and F regions of the tropical ionosphere have been clarified, such as, ionospheric transport phenomena between the dip equator and the latitude of F2 peak, equatorial electrojet and associated magnetic field variations, effect of solar flares and geomagnetic storms on the ionosphere etc.

(2) Experimental and theoretical studies of the effect of solar eclipses on the ionosphere.

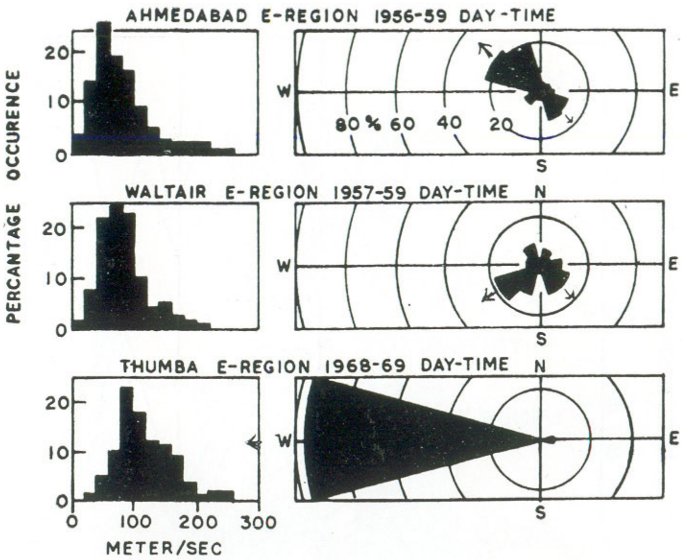
(3) Construction of equipment and study of wind drifts in the E and F regions of the ionosphere at Ahmedabad and Thumba.

The predominence of westward electron drifts during daytime and of eastward drifts during nights over Thumba was an important discovery made through this activity.



Seasonal and solar cycle variations of the maximum and minimum values of the total electron content obtained during a day at Ahmedabad

(4) Study of the absorption of radio waves reflected from the ionosphere (a) using ground-based transmitters and receivers, and (b) monitoring the intensity of galactic radio noise. (c) Construction and installation of equipment for the study of absorption in the D region by the partial reflection of vertically transmitted radio waves. (d) Study of many special phenomena connected with the equatorial electrojet. (e) Construction and use of a back-scatter radar to study irregularities in the electrojet over Thumba. (f) Monitoring field strengths of 164 kHz radio transmissions from Tashkent.



Directions and magnitudes of electrons associated with wind drifts in the daytime **E**–*region of the ionosphere*

In addition to the above, analytical and theoretical studies have been carried out of solar and lunar tides in the ionosphere over India and other parts of the world, and of the contribution of magnetospheric current systems to the enhanced daily variation of geomagnetic field in the electrojet region. At the equatorial electrojet stations, a number of interesting phenomena related to the occasional depression of the geomagnetic H field during daytime hours below the nighttime level have been discovered. Under those conditions ionospheric electron drift direction is changed from westward to eastward, the E_s type sporadic E layer is completely suppressed, and the height of ionization peak in the F2 region is reversed. There is evidence to show that these are connected with magnetic and electric field changes in interplanetary space.

IONOSPHERIC STUDIES WITH ROCKET–BORNE EQUIPMENT

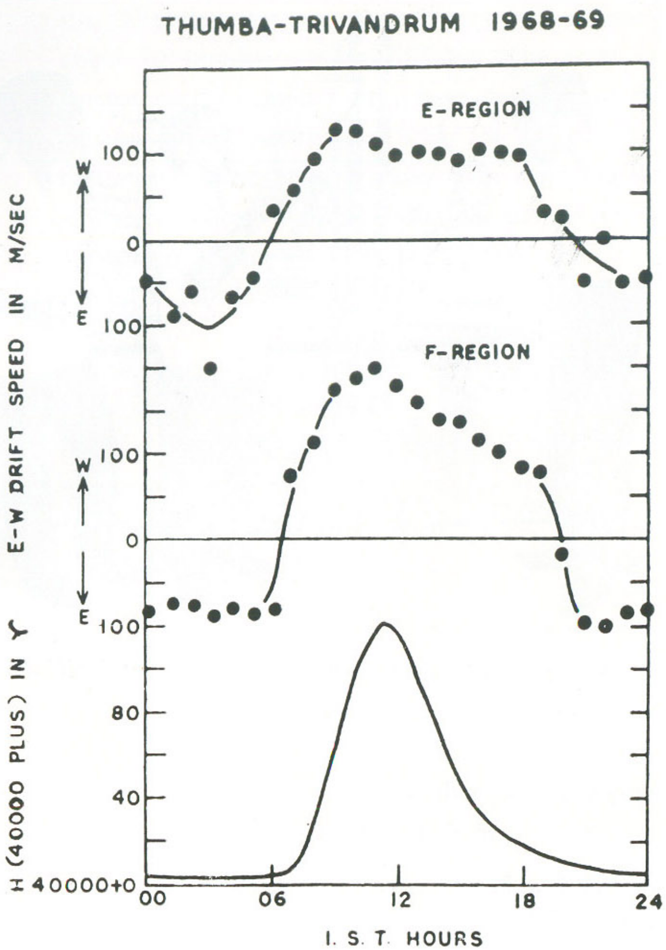
P.R.L. scientists have been involved both in building up ground–based facilities at Thumba and also in making instrumented payloads for use in rockets. The rocket studies include

(1) Measurements of wind, turbulence, and diffusion of particles in the height region 100–180 km using sodium and tri–methyl–aluminium vapour clouds, and electric fields from 100 to 250 km using barium–strontium clouds.

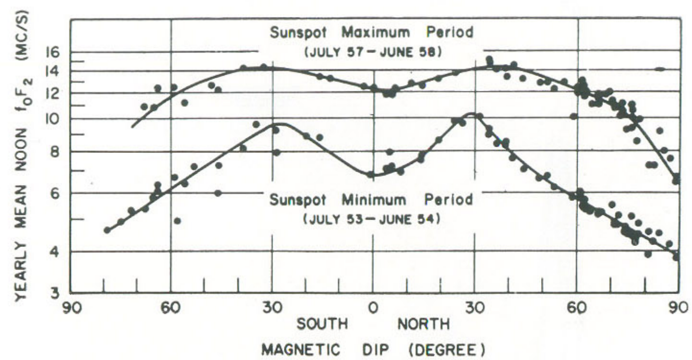
(2) Electron density profiles, electron and ion temperatures, energy distribution of ions and electrons etc. in the ionosphere, using different types of probes such as Langmuir probe, Resonance probe, Capacitance and Impedence probes, Retarding Potential Analyser etc.

(3) Magnetic field measurements at different levels using a proton precession magnetometer.

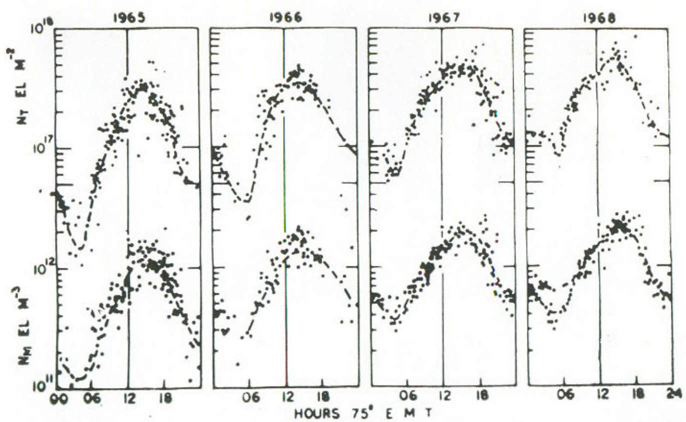
(4) Profiles of molecular oxygen in the ionosphere using Ly α ion chamber. Night–time Ly α flux and ultra–violet glow of atomic oxygen.



Variation of electron drifts in the ionosphere, and of the geomagnetic H–field near the magnetic equator



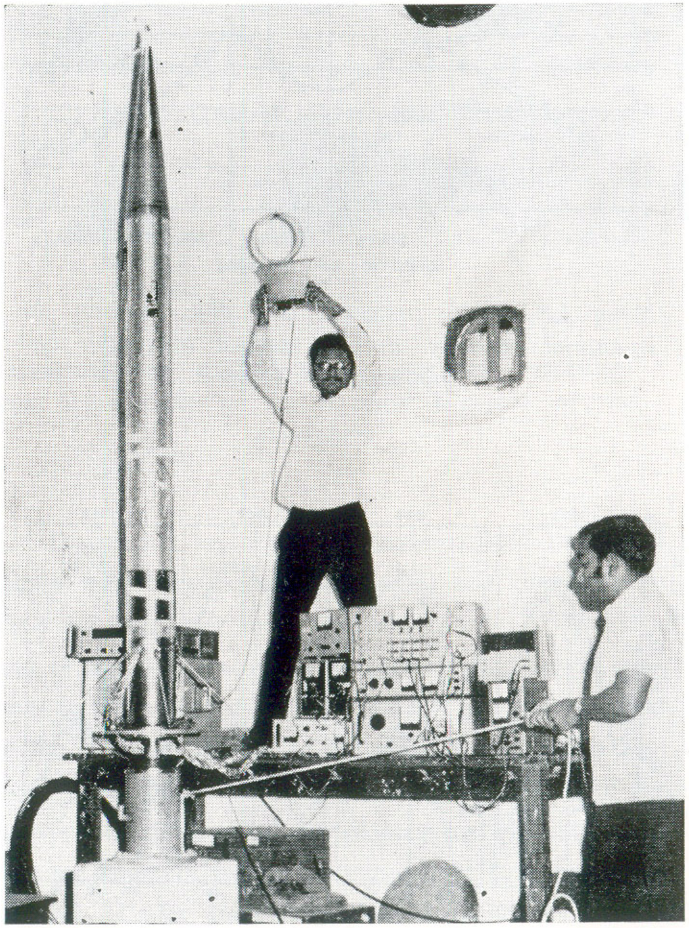
Noon f_0F_2 versus magnetic dip plot showing the equatorial anomaly during sunspot maximum and minimum conditions



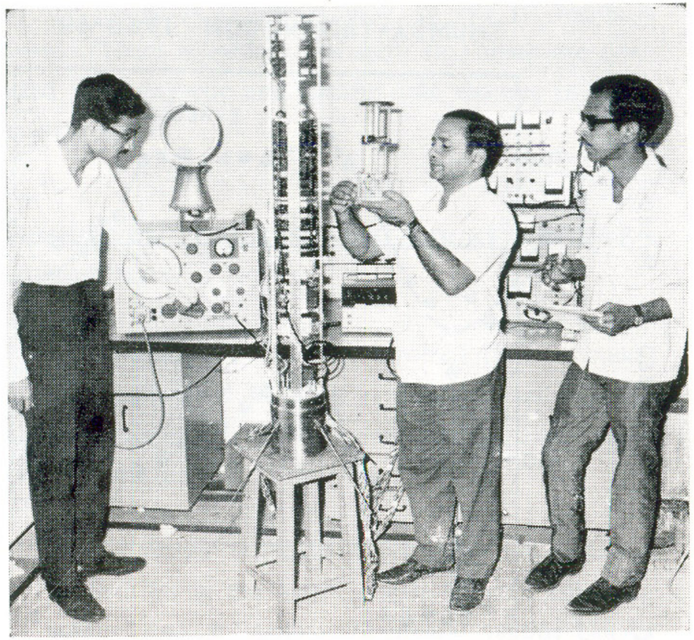
Daily variation of total electron content and maximum electron density in the ionosphere over Ahmedabad during summer season

(5) Electron density and electron collision frequencies in the D region by radio propagation experiments between rocket and ground.

(6) Photometry of 5577 air–glow using a rocket pay–load.



Radio Propagation Receiver Payload calibration during shock test



Assembly of rocket multiple payload at THUMBA

A few important results of these studies are given below :

(a) Langmuir probe measurements at Thumba have shown the presence of a layer of ionisation around 60 km with peak electron densities of a few tens of electrons per cc around noon. During evening twilight, a layer of enhanced electron density in the 130–140 km height region (E_s layer) has been found to be associated with enhanced electron temperatures.

(b) The electrojet current reaches a maximum of about 10 amp/km^2 around 105 km. The electrojet current peak is about 8 km above the peak of the equatorial Hall polarisation field. The value of the east–west electric field increases with height in the electrojet region. It increases from 0.2 mv/m at 100 km to 0.5 mv/m around 110 km and to 1 to 2 mv/m at 150–250 km.

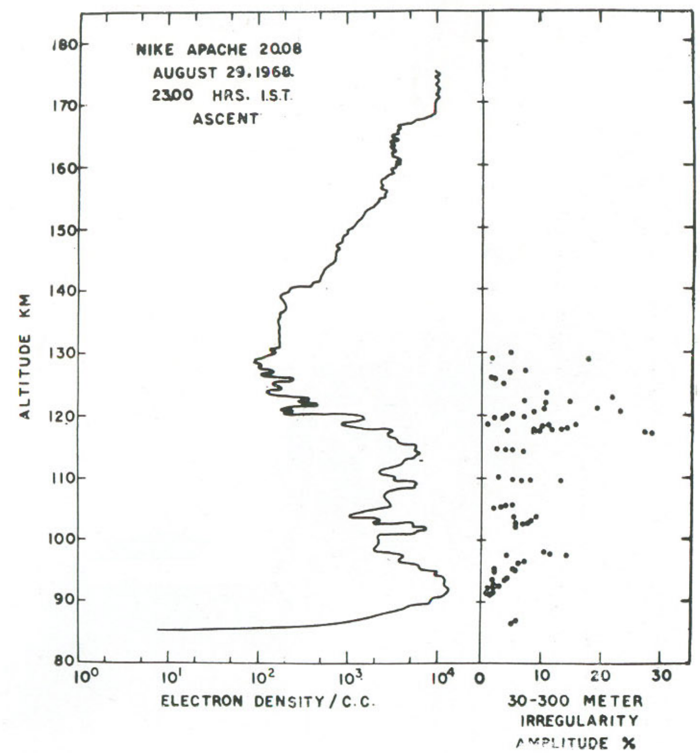
(c) A Langmuir probe with high frequency response which has been developed in P.R.L. has been used to study the ionisation irregularities in the height region 70–180 km at Thumba. The detected irregularities have been classified according to their scale sizes and production mechanisms.

Irregularities produced by crossfield instability are observed in the regions where electron density gradient and vertical Hall field are parallel. During day–time they are seen in regions of positive density gradient and during night time in the regions of negative electron density gradient.

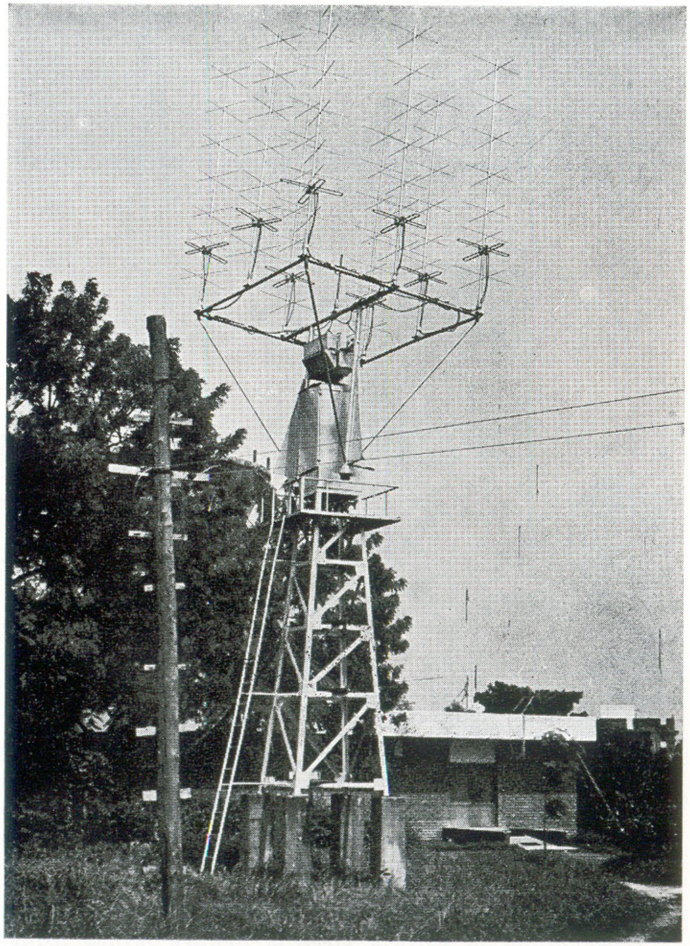
Irregularities are observed at about 105 km where electrojet currents reach their peak. Their scale sizes lie in 1–15 meter range.

Irregularities are also observed at 70–80 km where neutral turbulence and large electron density gradients exist.

(d) Strong wind shears are found in the height region 100–115 km. Turbulence disappears above 110–115 km. The zonal winds are predominently westward in the height region 115–140 km and eastward above 140 km. The meridional component shows irregular variations up to 150 km, but above 150 km, it is mostly northward. The wind speeds reach values up to 100 m/s and show a diurnal variation between 130 and 150 km, being stronger in evening than in morning.



Irregularities in vertical electron density profile using a rocket payload



Satellite Telemetry Antenna

SATELLITE TELEMETRY AND SOUNDING OF THE TOPSIDE OF THE IONOSPHERE

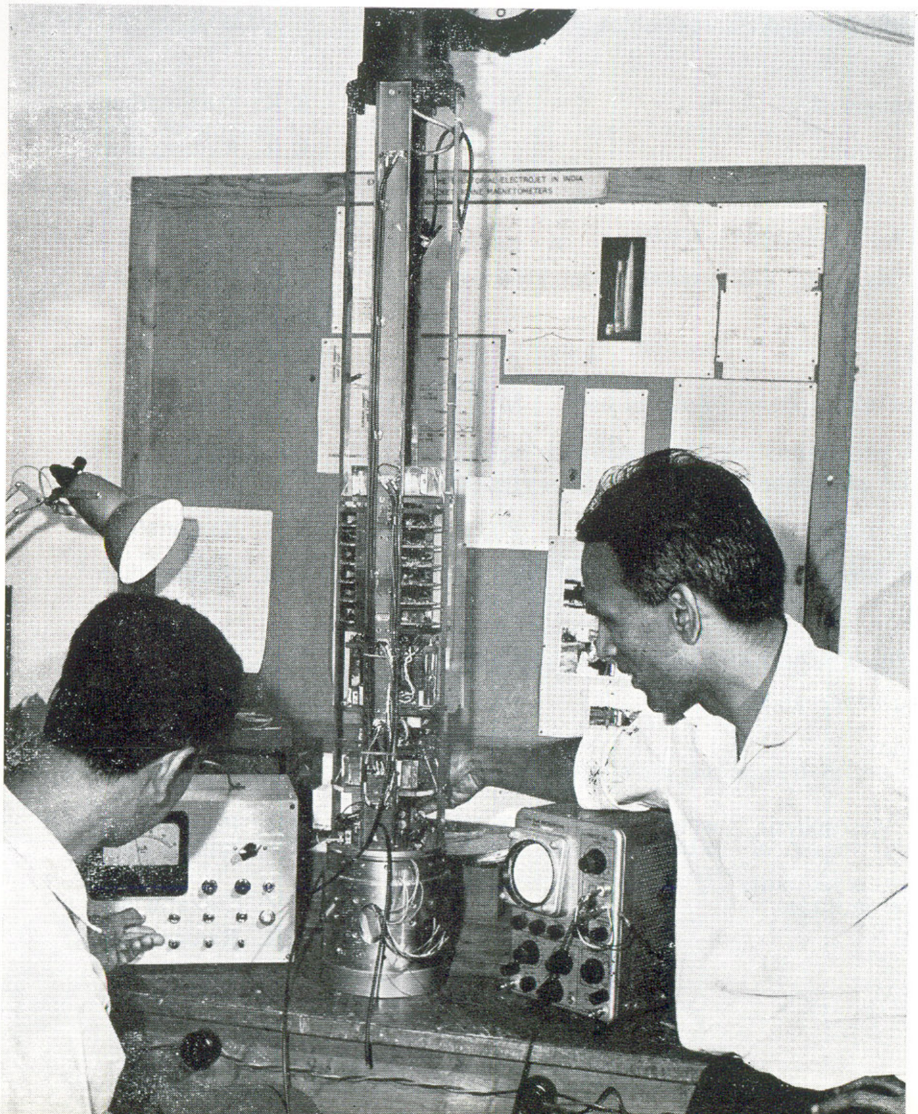
A satellite telemetry station was installed at Ahmedabad in 1961 with NASA collaboration. Recordings of the Faraday rotation of 20, 40 and 41 MHz transmitted by the U.S.A. satellites BE–B and BE–C were regularly recorded from 1964 onwards and the data analysed to determine the total electron content of the atmosphere up to the satellite height of about 1000 km. These have been compared with the maximum electron density at the peak level of the F_2 region.

In 1968–70 equipment for obtaining topside ionosonde data of the Canadian satellite Alouette II and ISIS–I and II was installed at Ahmedabad. The records are analysed to obtain the profiles of electron density above the levels which can be monitored from ground. We are thus able to get the electron density distribution from the ground to 1000 km over a range of latitudes centred at Ahmedabad.

A list of research scholars who obtained M.Sc. or Ph.D degrees by work at P.R.L. in Aeronomy and Geomagnetism follows.

The main research workers in this area have been R. G. Rastogi, K. M. Kotadia, J. S. Shirke, S. S. Degaonkar. P. D. Bhavsar, J. N. Desai, Satya Prakash, T. S. G. Sastry, B. Subbaraya, R. Raghava Rao and their students.

Integration of Rocket Payload for electron density and magnetometer measurements



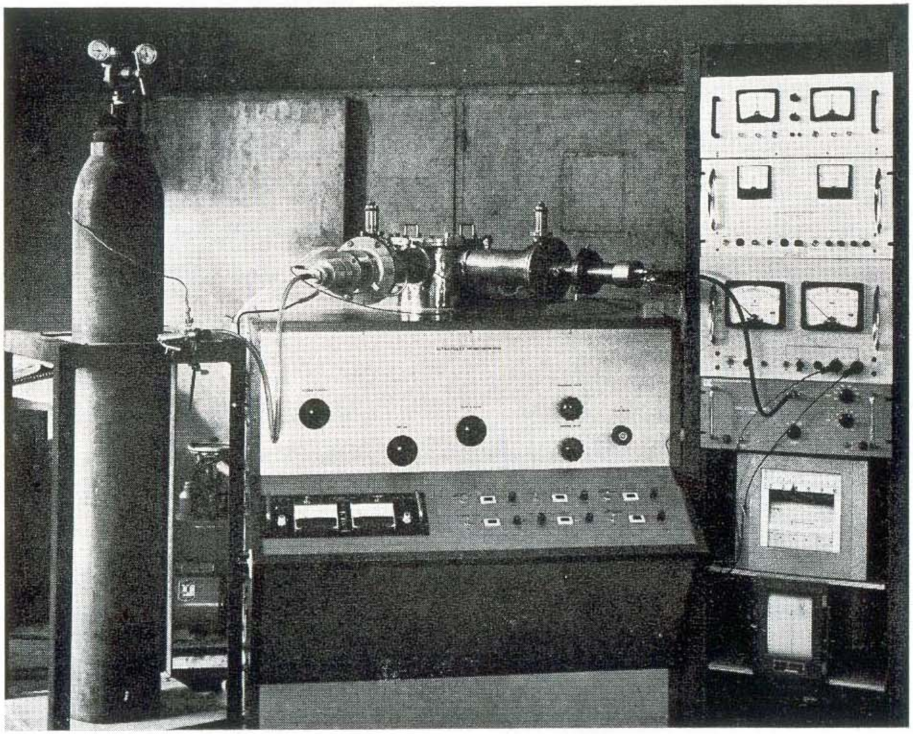
Colonel Laclavere, Prof. K. R. Ramanathan and Prof. J. T. Wilson

	AUTHOR	TITLE OF THE THESIS	DEGREE (YEAR)	RESEARCH GUIDE
		METEOROLOGY, OZONE AND AIRGLOW		
1.	R.V. Karandikar	Studies in atmospheric ozone and radiation balance in the atmosphere.	Ph.D (1949)	K.R. Ramanathan
2.	J.V. Dave	Studies in brightness and polarisation of sky during twilight.	M.Sc. (1953)	K.R. Ramanathan
3.	R.N. Kulkarni	Day–to–day changes in the amount of the vertical distribution of atmospheric ozone over Mt. Abu.	M.Sc. (1953)	K.R. Ramanathan
4.	V.G. Jani	Polarisation of the sunlight sky.	M.Sc. (1953)	K.R. Ramanathan
5.	Bh. V. Ramana Murthy	Studies in atmospheric ozone.	Ph.D (1953)	K.R. Ramanathan
6.	S.R. Shah	Studies in low level atmospheric turbulence in Ahmedabad. Variation of wind with height.	M.Sc. (1954)	K.R. Ramanathan
7.	V.C. Upadhyaya	Temperature and winds near the ground over Ahmedabad.	M.Sc. (1955)	K.R. Ramanathan
8.	S.V. Venkateswaran	Studies in Meteorology.	Ph.D (1955)	K.R. Ramanathan
9.	S.S. Degaonkar	Vertical distribution of atmospheric ozone in low latitudes.	M.Sc. (1955)	K.R. Ramanathan
10.	J.V. Dave	Studies on twilight and atmospheric ozone.	Ph.D (1957)	K.R. Ramanathan
11.	R.N. Kulkarni	Studies in atmospheric ozone.	Ph.D (1959)	K.R. Ramanathan
12.	B.S. Dandekar	Observations of night airglow at Mt. Abu and their discussion.	Ph.D (1961)	K.R. Ramanathan
13.	G.M. Shah	Atmospheric studies by optical scattering.	Ph.D (1962)	K.R. Ramanathan
14.	P.D. Angreji	Studies in atmospheric ozone and airglow.	Ph.D (1967)	K.R. Ramanathan
15.	S.R. Pal	Studies in Night Airglow.	Ph.D (1968)	K.R. Ramanathan & P.V. Kulkarni
16.	M.S.V. Rao	Stratospheric and Mesospheric winds over Thumba.	Ph.D (1970)	P.R. Pisharoty
17.	V.R. Rao	Airglow studies in low latitudes.	Ph.D (1971)	P.V. Kulkarni & K.R. Ramanathan

AUTHOR	TITLE OF THE THESIS	DEGREE (YEAR)	RESEARCH GUIDE
	IONOSPHERE AND GEOMAGNETISM		
1. N.G. Nanda	Study of winds in the ionosphere over Ahmedabad.	M.Sc. (1955)	K.R. Ramanathan
2. R.G. Rastogi	Studies in the Physics of the Ionosphere.	Ph.D (1956)	K.R. Ramanathan
3. K.M. Kotadia	Studies in the Physics of the Ionosphere in low latitudes.	Ph.D (1958)	K.R. Ramanathan
4. R. Sethuraman	Study of the Ionospheric wind drifts over Ahmedabad.	Ph.D (1959)	K.R. Ramanathan
5. R.V. Bhonsle	Studies in Ionospheric Physics using extra-terrestrial Radio Noise.	Ph.D (1960)	K.R. Ramanathan
6. S.R. Sreenivasan	Distribution of electrons in the Ionosphere from vertical soundings.	Ph.D (1960)	K.R. Ramanathan
7. S.S. Degaonkar	Vertical distribution of electrons in the Ionosphere over Ahmedabad.	Ph.D (1961)	K.R. Ramanathan
8. J.S. Shirke	Investigations on the physics of the Ionosphere over Ahmedabad.	Ph.D (1962)	K.R. Ramanathan
9. S.K. Alurkar	Ionospheric studies by reflected electromagnetic waves.	Ph.D (1963)	K.R. Ramanathan
10. M.A. Abdu	Galactic radio noise alternation in the ionosphere.	Ph.D (1966)	K.R. Ramanathan
11. K. Ramanuja Rao	Dissertation on studies in upper atmosphere: measurement of neutral atmosphere winds above 80 km.	Ph.D (1966)	P.D. Bhavsar

	AUTHOR	TITLE OF THE THESIS	DEGREE (YEAR)	RESEARCH GUIDE
12.	C.M. Patel	Studies of horizontal drifts in the ionosphere over Ahmedabad.	Ph.D (1966)	K.R. Ramanathan & R.G. Rastogi
13.	S. Sanatani	Electron density distribution in the ionosphere	Ph.D (1966)	R.G. Rastogi & K.R. Ramanathan
14.	M.R. Deshpande	Ionospheric drift measurements over low latitudes.	Ph.D (1966)	K.R. Ramanathan & R.G. Rastogi
15.	S. Ananthakrishnan	Studies of the propagation of low frequency radio waves in the ionosphere.	Ph.D (1967)	K.R. Ramanathan
16.	S. Ramakrishnan	Beacon satellite studies on the ionosphere over Ahmedabad and neighbouring low latitudes.	Ph.D (1967)	K.R. Ramanathan
17.	B.H. Subbaraya	Studies in equatorial aeronomy: Langmuir probe studies of the lower equatorial ionosphere at Thumba.	Ph.D (1968)	Satya Prakash
18.	Harishchandra	Studies of low latitude ionosphere.	Ph.D (1969)	R.G. Rastogi
19.	S.P. Gupta	Study of the lower ionosphere at low latitudes.	Ph.D (1970)	Satya Prakash & V.A. Sarabhai
20.	N.D. Kaushika	Studies of ionization irregularities in E–region of the Ionosphere over low latitudes.	Ph.D (1971)	R.G. Rastogi
21.	R.K. Misra	Studies of the ionospheric irregularities at low latitudes.	Ph.D (1971)	R.G. Rastogi
22.	Girija Rajaram	Studies of disturbance in the F–region of the Ionosphere.	Ph.D (1971)	R.G. Rastogi

	AUTHOR	TITLE OF THE THESIS	DEGREE (YEAR)	RESEARCH GUIDE
23.	R.P. Sharma	Electron density variations in the ionosphere at low latitudes.	Ph.D (1972)	R.G. Rastogi
24.	S.C. Chakravarty	Studies of Radio wave propagation in the lower ionosphere.	Ph.D (1972)	K.R. Ramanathan & R.G. Rastogi



Ultra-violet Monochromator built in PRL

Nuclear Theory

The nuclear theory group has carried out extensive applications of the shell model, on the one hand to explain and predict many observed features of nuclear states in the whole range of the periodic table, and on the other hand to use it as a tool for exploring and elucidating the nature of the effective nucleon–nucleon force inside nuclei. A shell model analysis of the observed spectra of nuclei in d–s and f–p shells has shown that the interaction in relative s–states of two nucleons is the dominant component of the total interaction. This information coupled with the use of Hartree–Fock techniques and group–theoretic methods has given a very useful qualitative understanding of the major features, such as deformations and shapes, in d–s shell nuclei. For example, it is now possible to trace the origin and importance of the SU_3 symmetry in d–s shell nuclei to specific matrix elements of the realistic nuclear interaction rather than to fictitious quadrupole interactions.

We are studying the role of $T=1$ and $T=0$ components of the nuclear interaction in generating deformations in nuclei. It has been shown that, contrary to the popular notions, both these components are about equally effective in producing deformations, and have similar pairing characteristics.

Group–theoretic methods have been used to analyse the nuclear interactions and the coupling schemes in nuclei. The famous Kuo–Brown interaction has been shown to preserve SU_4 symmetry but to break the SU_3 symmetry for two particles in d–s shell, and the dominance of the SU_3 symmetry in the first half d–s shell and lack of it in f–p shell are shown to arise from the nature of the single–particle orbits and spin–orbit interaction. The powerful techniques of spectral distribution methods are being utilised for the first time to examine systematically various group symmetries of nuclear wave–functions.

Detailed analysis of the collective modes of excitations in nuclei and their origin in microscopic theories of nuclei has been another fruitful activity of this group. One of the first applications of the unified model (which combines single–particle dynamics and collective vibrations) to light nuclei in d–s shell was carried out here to explain the spectra and electromagnetic transitions in Silicon and Phosphorus isotopes. In recent years self–consistent–field methods (HF and HFB) have been used extensively to study the collective properties of a variety of nuclei. Our emphasis has been on extending the range of these methods by using excited deformed configurations and band–mixing to study high excited states of nuclei other than those of the ground band. As an example, the first collective model calculation for Ne^{24} has been done, including, besides the lowest HF configuration, several particle–hole excited configurations and shape–mixing. A good agreement has been obtained between calculated and observed spectra. Several additional states and electromagnetic properties are predicted.

Recently the generator coordinate method has been shown to give a comprehensive microscopic description of collective dynamics. This has been used to obtain successfully states in Ne^{20} upto an excitation energy of about 18 MeV, and is the first realistic practical demon–stration of the method.

A new method of generating intrinsic states of deformed nuclei, by minimising variance of the Hamil–tonian operator rather than only its expectation value (as in HF) is being developed.

The alpha–cluster model for light even–even N=Z nuclei has been studied and the role of the effective interaction (density–dependence, repulsion in odd states) in producing clustering is clearly demonstrated. These studies are being extended to heavy–ion reactions and fission processes.

Some aspects of elementary particles interacting with nuclei have been investigated. Analysis of electron scattering by Be^{9} showed the charge–distribution of s–shell protons to be more compact than that of p–shell protons. Pion–capture in He^{3} and Li^{6} has been studied to obtain information on correlations in nuclei.

The principal workers in this field have been Bhatia, Vachaspati, S. P. Pandya, K. H. Bhatt, J. C. Parikh, S. B. Khadkikar and their students. A list of research scholars who obtained Ph.D. degree in this area follows :

	AUTHOR	TITLE OF THE THESIS	DEGREE (YEAR)	RESEARCH GUIDE
1.	V.K. Thankappan	Collective vibrations in light nuclei.	Ph.D (1962)	S.P. Pandya
2.	Y.R. Waghmare	Theoretical studies in the structure of light and intermediate nuclei.	Ph.D (1962)	S.P. Pandya
3.	S.K. Shah	Studies in structure and properties of light nuclei.	Ph.D (1963)	S.P. Pandya
4.	Miss M.S. Shah	Studies of Pion–capture in three–body systems ^{3}He and ^{6}Li.	Ph.D (1969)	S.P. Pandya
5.	D.R. Kulkarni	The Effective Interactions and Deformations in 1d–2s and 1f–2p shells.	Ph.D (1972)	S.P. Pandya
6.	S.K. Sharma	Deformations, pairing and Effective Interactions in Nuclei.	Ph.D (1973)	K.H. Bhatt

Plasma Physics

The study of plasma physics in all its aspects undoubtedly constitutes an integral part of the overall space research programme of the laboratory — it can in fact be considered as a natural extension of the work of P.R.L. in the field of aeronomy. Almost all the experimental studies being carried out here are intimately related to the properties of plasma in various parameter ranges. Thus an understanding of the various ionospheric, magnetospheric, galactic, solar and geomagnetic phenomena cannot be achieved without a corresponding understanding of basic plasma processes. Dr. Vikram Sarabhai realised this and started a Plasma Physics Group at P.R.L. in late nineteen sixties. He also realised that since fusion is the ultimate answer to the future power requirements of mankind, India should develop a core of trained plasma physicists and technologists who would be able to take up fusion work in earnest, as and when its feasibility is demonstrated elsewhere in the world.

The plasma physics group is working on problems of space plasmas, fusion plasmas and solid state plasmas.

A variety of problems involving linear instabilities of plasma oscillations are studied. For example, electrostatic and electromagnetic instabilities which can be excited in the equatorial electrojet are needed to explain the electron density irregularities observed by rocket and back-scatter measurements by the aeronomy group. Electromagnetic streaming instabilities in nonuniform anisotropic plasma embedded in inhomogeneous magnetic field are studied to explain solar wind observations by space-crafts and turbulent heating in Tokomaks.

To see where the solar wind terminates in the interplanetary medium, the low frequency instabilities arising due to interaction of the solar wind with the neutral interplanetary gas are studied. In cosmic ray plasmas and in some fusion plasmas, the energies encountered are relativistic; new instabilities arising in such relativistic plasmas are explored.

Several non-linear phenomena of relevance to space and fusion plasmas are investigated. Thus irreversible statistical mechanics techniques are used to obtain non-linear dielectric properties of an electron gas in a magnetic field, and the results have been applied to solar radio bursts (experimental observations of the Radio Astronomy group) and de Haas–Van Alphen oscillations in metals. Light filamentation in a dense plasma has been investigated and applied to laser heating of plasmas.

Non–linear wave–particle interactions in a large amplitude whistler mode have been studied to explain the observed VLF emissions. Study of non–linear wave–interactions has led to the exciting result that a plasma with drifting electrons could be used for coherent production of electromagnetic waves of frequency conventionally difficult to generate. In other words, a plasma laser or maser could be possible.

Most plasmas in nature and in laboratory are turbulent. Turbulence can give rise to anomalously large transport coefficients. Effects of turbulence and toroidal electric fields on diffusion and thermal conductivity of a plasma in Tokomak has been investigated.

The effect of high frequency waves in a plasma is analysed to see if the unwanted low–frequency macroscopic instabilities can be suppressed or if some new microscopic turbulence can be introduced which would be useful to improve heating efficiency of the plasma. The results are applied to external control of irregularities in electrojet, and anomalous absorption of radio waves in the ionosphere.

Problems of diffusion, deceleration and other physical processes seen in barium cloud release experiments, carried out at Thumba, have been theoretically studied. Geomagnetic studies require a critical understanding of current systems in the ionosphere. A three–dimensional model of the magnetospheric dynamo system has been formulated.

Non–adiabatic escape of charged particles confined by inhomogeneous magnetic fields is studied by formulating a Schrodinger–equation for the process.

Some work is being done on quantum plasmas. Collective oscillations of electrons in metals can give rise to new atomic levels above the ionisation energy. Using the Thomas–Fermi model it has been demonstrated that such oscillations have lifetimes long enough to be physically meaningful. These results are applied to inelastic energy losses seen in atom–ion scattering experiments.

A re–examination of the fundamental concepts of quantum mechanics has been undertaken to find a connection between the probability as used in quantum theory and that of classical statistics. A new derivation of the Schrodinger equation has been proposed.

The Experimental Plasma Physics Group has begun setting up a laboratory experiment for the study of cross–field streaming and gradient instabilities. These instabilities are of importance in understanding the generation of density irregularities in the equatorial ionosphere — a problem which has been studied intensively by the rocket aeronomy group at P.R.L.

The principal workers in this field have been Miss B. Buti, P. K. Kaw, A. C. Das, R. K. Verma, R. Pratap, A. Sen, A. K. Sundaram, P. I. John and their students.

Cosmo-geo-physics

In the field of Cosmo-geo-physics which has been started in P.R.L. with the arrival of Professor D. Lal as Director, the main programmes are: (i) Nuclear Cosmo-physics including nuclear reactions and solid state damage due to galactic and solar cosmic radiation and natural transmutations. These studies are aimed at a delineation of both the radiation history of cosmic rays as well as the history of irradiation of extra terrestrial materials in space. (ii) Nuclear Oceanography i.e. radio-isotope tracer methods for studying ocean dynamics and geological and cosmological records, and (iii) Mass-spectrometry studies of minute quantities of gases, cosmogenic and radiogenic, to decipher cosmic and geological chronology.

The programmes dealing with nuclear cosmophysics involve study of Lunar samples returned up to the last Apollo Mission (Apollo 17). Professor D. Lal has been approved as a Principal Investigator of NASA. The group is also investigating lunar samples brought to earth by Luna 16 and 20 missions and supplied by the USSR Academy of Sciences to the Indian National Science Academy.

Theoretical investigations are being carried out at the Physical Research Laboratory in the fields of Cosmo-logy and Oceanography. The effects of irradiation by cosmic rays of small objects in free space or on a parent body are studied. Dramatic differences have been found which could be put to use for delineation of the exposure history of extra-terrestrial samples. In the field of oceanography, a new area of research has been opened up as a result of studies of naturally and artificially pro-duced (man-made) radioactivities in ocean-sediments. These results find applications in trace element geo-chemistry and sedimentation in lakes and near coastal regions of the oceans.

Archaeology and Hydrology

The Archaeology–Hydrology group which was in TIFR till 1972 has now come to P.R.L. and is being expanded. A C^{14} laboratory has been set up and faci-lities for Si^{32} and H^{3} measurements will soon be added It is proposed to increase the activities of the Archaeo-logy group by adding archaeological metallography and study of ancient tool techniques and sedimentology and enstatic changes of water levels in the Runn of Kutch.

In Hydrology, work has been started on the ground-water problems of Ahmedabad and the water balance of the Sabarmati basin.

Remote Sensing of Earth Resources

The UN Conference on the Peaceful Uses of Outer Space, held at Vienna in August 1968, high-lighted the applications of remote-sensing techniques from aircraft and spacecraft platforms for surveying the resources of the earth. Dr. Sarabhai who was the Scientific Chairman of the Conference, created a cell in the P.R.L. to deal with the use of Space Technology for the remote-sensing of natural resources in India and promoting necessary follow-up action. This small cell has now expanded and become an important Division of the Space Applications Centre, Ahmedabad under Dr. P. R. Pisharoty.

Computer Centre

Supporting Facilities

TECHNIQUES AREA

Two service groups, namely the Electronics laboratory and the Techniques laboratory, were established in mid–sixties. These laboratories were entrusted with the responsibility of developing new instrumentation for the use of various scientific groups and to run sophisticated centralised facilities. They are now merged into a larger "Techniques Area".

The area also collects literature and expertise on front rank techniques and devices likely to be of use for the future programmes of the laboratory.

Since the inception of the electronics laboratory a large number of instruments have been designed and fabricated for the use of the various groups. The production of equipment has been restricted largely to those items which are not readily available in the open market. Initially transistorised power supplies of various designs were produced in large numbers. These included regulated supplies with small and large current ratings in single or double modules and D.C. to D.C. converters with low as well as high voltage outputs. More recently the emphasis has been shifted to very high voltage power supplies which are not commercially available.

Some of the other units manufactured by this group include pulsers with varied specifications, scalers with a wide range of scaling factors, dual preset frequency counters as well as frequency meters. Crystal controlled digital clocks and data acquisition systems have been designed and fabricated long before they were available in the open market. The know–how for some of these units has also been passed on to industry for mass production.

The group supplies printed cards for the construction of sophisticated equipments. Electroplating and component lay–out is also undertaken. The group services electronic equipment used in the laboratory, tests new equipments procured, and maintains centralised facilities such as public address systems, tape recorders, pulse height analyser, storage oscilloscope, admittance bridge etc.

The group undertakes training of Research Scholars in electronics and has also been helping the Gujarat University in teaching of the post graduate course in electronics.

Demands for construction and design of various types of new equipments are on the increase and it is expected that this group would be the main centre of electronic activity in the laboratory in near future.

The techniques laboratory has been looking after environmental testing of pay–loads, epoxy potting of electronic circuits, water distillation plant, glass blowing for various requirements, vapour degasing, ultrasonic cleaning of small articles and such other centralized facilities.

One of the major programmes of the techniques group has been in the area of vacuum deposition and production of thin film interference filters. Demands for good quality filters are on the increase both inside and outside the laboratory. The facility is being expanded to produce filters for use in the ultra violet as well as in the infra red regions.

Currently, the major thrust of the techniques group has been on the development of vacuum and Ultra–high vacuum systems as these find many applications in the scientific programmes of Aeronomy, Plasma, Geo-cosmo and other groups in the laboratory. The group is also working on developing new devices of importance such as channeltrons.

COMPUTER CENTRE

A Computer Centre with an IBM 1620 computer was established in P.R.L. in 1962. In the initial stage, we had only 20K core storage, but in 1967, a core storage of 40K was added so as to use the maximum memory availability of the system. The need for a larger system was soon felt in order to keep pace with the growing needs of the computer users. On the 25th June 1972, the IBM 360/44 system was installed. The system consists of 256K bytes of main memory, a card reader (1000 cards/minute) as main input unit, an on-line printer (1100 lines/minute) as the main output unit, two magnetic tape devices and two magnetic disk devices.

Being a service-oriented centre, it caters to the computing needs of the different projects of PRL as well as of other educational institutions and is also available to commercial users.

The activities of the Computer Centre are divided into five groups, 1) Numerical Analysis Group, 2) Operational and Statistics Group, 3) Applications Group, 4) Systems Group and 5) Commercial Group. Facilities for writing programmes for outside users are also provided by the Centre. A course for programming is being conducted every year during the summer vacation for the benefit of graduates of universities who wish to learn computer programming. About 30 academic and research organisations and an equal number of commercial and industrial groups are now making use of the computer facilities in P.R.L.

The initiative of Dr. Sarabhai, and the expert knowledge and energy of Shri S. R. Thakore, have been responsible for the build-up of the computer facilities not only in P.R.L., but also in other Space Centres in the Country.

LIBRARY

The number of books and journals in the P.R.L. library as well as the library space have steadily grown over the years.

The Library is now housed on the first floor of the newest building. It has a floor space of 3136 sq. ft. Even this space is found to be insufficient and additional space is being provided on an upper floor.

The Library receives 295 Scientific and Technical Journals. Twelve selected periodicals are received by airmail. The total stock of books and bound volumes of periodicals is now over 11,400.

A catalogue of books in the Library has been compiled and put in machine-readable form, so that the data base can be used for search of references. The number of access points to the bibliographical groupings have been increased. A 'Catalogue of PRL Publications 1948-1972' and a 'Catalogue of Periodicals' received in the library have been compiled. The Library has also

made a beginning towards the compilation of computerised indexes.

From about 50 members in 1961, the Library has now on its rolls 400 members. Besides, many students and teachers from the University and Colleges visit the Library for reading and studying. The Library is open for 13½ hours on each working day, and for 7 hours on closed Saturdays, Sundays and Holidays.

Adequate facilities for photo-copying and reproduction of documents have been provided. Two Microfilm Readers are available in the Library. A photo-copying machine has been installed.

Educational Activities

Since the inception of PRL, it has been one of the objectives to associate research students with various research programs, and to develop the laboratory as a post-graduate centre for basic research and training in experimental and theoretical physics. This program has resulted in building up groups of trained scientists and technologists who have played a vital role in the establishment of space research activities in India. A large part of the research Faculty at PRL has indeed received its early training here. Many research scholars, after receiving their Ph.D., have gone to universities and other research organisations, not only in India but also in other countries. About eighty students have obtained research degrees (M.Sc. or Ph.D.) based on their work at PRL during the last twenty-five years. About 40 scholars are at present working towards Ph.D. here at present.

Various faculty members at PRL have also from time to time given extended lecture courses to post-graduate students of other universities around us, such as the Gujarat University at Ahmedabad, Sardar Patel University at Vallabh Vidyanagar and M.S. University at Baroda. The Laboratory has played an active role in helping the Gujarat University to set up a post-M.Sc. course on Space Science and Applications by providing teaching as well as laboratory facilities. The Computing Centre has similarly run regularly classes on computing science for University students as well as Industries and Business firms, and is now helping the Gujarat University to set up its own computer education programs.

At the initiative of Dr. Vikram Sarabhai, a Group for Improvement of Science Education was started as a part of PRL program in 1961. This has now developed into an autonomous Vikram Sarabhai Community Science Centre located close to PRL with its own scientific staff, laboratories and workshop. The centre has several extensive programs aimed towards improved teaching methods and aids for school and college students.

A Tribute to Prof. K. R. Ramanathan

There are a few individuals in any country who give much more to the society than what they take from the society. Such an attitude is particularly necessary for leadership in science, which really consists of providing a liberal and understanding environment enabling others to develop their talents. Professor Ramanathan has been such a self–effacing leader in science. The Physical Research Laboratory has been fortunate in securing his services throughout the last twenty five years — first as its Director for more than two decades, and now as Professor Emeritus and Chairman of the Laboratory's Council of Management.

Dr. Sarabhai and Dr. Ramanathan had together planned the setting up of such a Laboratory at Ahmedabad in the early forties, when Dr. Sarabhai was at the Meteorological Office, Poona conducting his cosmic–ray experiments. Dr. Ramanathan joined the Laboratory as its Director in March 1948, after serving the India Meteorological Department with distinction for several years.

During his career in the India Meteorological Department he had been studying the meteorology and aeronomy over India as an integral part of a global system and this view was pursued with greater vigour as Director of PRL. The world scientists recognised this and elected him first as President of the International Association of Meteorology (1951–54) and later as the President of the IUGG (1954–57). In these capacities he played an active role in planning for the measurements of geophysical parameters throughout the globe with standard instruments, during the IGY. The Laboratory thus became an internationally recognised centre participating in the IGY.

His contributions as a member of PRL in the field of meteorology, atmospheric ozone, twilight and airglow, ionosphere and radio astronomy have been described elsewhere in this volume.

Professor Ramanathan completed 25 years of service in the Laboratory as he turned eighty, and continues to guide the activities of the laboratory in his present capacity as Professor Emeritus and Chairman of the Council of Management for the Laboratory.

We wish to convey to him our sincere thanks for all that he has done and is doing for the progress of PRL.

The World Meteorological Organisation awarded to Prof. K. R. Ramanathan the International Meteorological Organisation Prize for 1961 "in recognition of his distinguished contributions to the aerology of the tropical and sub-tropical regions and in particular the Indian Monsoon region. His studies on Atmospheric Ozone in relation to the general circulation of the atmosphere: his furtherance of research in many allied branches of the physics of the High Atmosphere and his services to the cause of International collaboration in Meteorology and other geophysical sciences".

Acknowledgements

The Physical Research Laboratory gratefully acknowledges the sympathetic co-operation of sister organisations, both in India and abroad, during the past twentyfive years, and looks forward to similar collaboration in the years to come.

Outstanding scientists have visited, lectured and participated in our work; they have also provided advice and encouragement. The Laboratory wishes to record its gratitude to these distinguished personalities. A brief account of such visits is given in the next section: Distinguished Visitors.

Some of the National Institutions who have extended their co-operation are :

Council of Scientific and Industrial Research
Department of Atomic Energy
Tata Institute of Fundamental Research, Bombay
Vikram Sarabhai Space Centre, Trivandrum
India Meteorological Department
Indian Institute of Geomagnetism, Bombay
Indian Institute of Astrophysics, Kodaikanal
National Physical Laboratory, New Delhi
Gujarat University, Ahmedabad
Institute of Radiophysics and Electronics, Calcutta
High Altitude Research Laboratory, Gulmarg
Saha Institute of Nuclear Physics, Calcutta
Department of Physics, Andhra University, Waltair

In the early stages of development of new fields of science, PRL needed technical assistance from friendly developed nations. This was particularly so in the area of Space Sciences. We received such assistance in abundant measure. We had (and continue to have) collaborative programmes with :

NASA, MIT, AFCRL (USA)
CNES (France)
Hydromet Service & Academy of Sciences (USSR)
Max Planck Institute (FDR)
Space Research Council & British Met. Office (UK)
Tokyo University (Japan)

Distinguished Visitors

Outstanding scientists have visited, lectured and participated in our work. A list of our distinguished visitors is given below :

1. **Prof. S. Chapman** (Dec. 1948)

   Gave a course of lectures on Geomagnetism, the Upper Atmosphere and Aurorae.

2. **Prof. H. V. Neher** (Oct. 1955 to April 1956)

   Lectured on Cosmic Rays, their geophysical and cosmical aspects — guided Satya Prakash to build all–metal vacuum systems and in the use of boron tri–methyl for preparing neutron counters.

3. **Dr. G. Clark** (June-July 1956)

   Set up Shower experiment at Kodaikanal; E. V. Chitnis worked with him.

4. **Prof. H. Alfven** (Dec. 1957)

   Lectured on Cosmical Electrodynamics and Cosmic influences on the earth.

5. **Prof. S. Chandrasekhar** (Oct. 1961)

   Lectured on "Hydrodynamic and Hydromagnetic Stability".

6. **Prof. A. J. Dessler** (Sept. 1961 to Jan. 1962)

   Worked with PRL research workers on various problems of the Upper Atmosphere, Magnetosphere and Space Physics.

7. **Prof. J. V. Narliker** (Dec. 1968 to Mar. 1969)

   Lectured on "Extra Galactic Astronomy and Cosmology" and on "General Relativity & Gravitation".

8. **Prof. A. P. Willmore** (Oct. 1969 to Jan. 1970)

   Lectured on Morphology and Dynamics of the Ionosphere. Conducted rocket experiments in collaboration with PRL scientists.

9. **Prof. McCracken** (Winter of 1970-71)

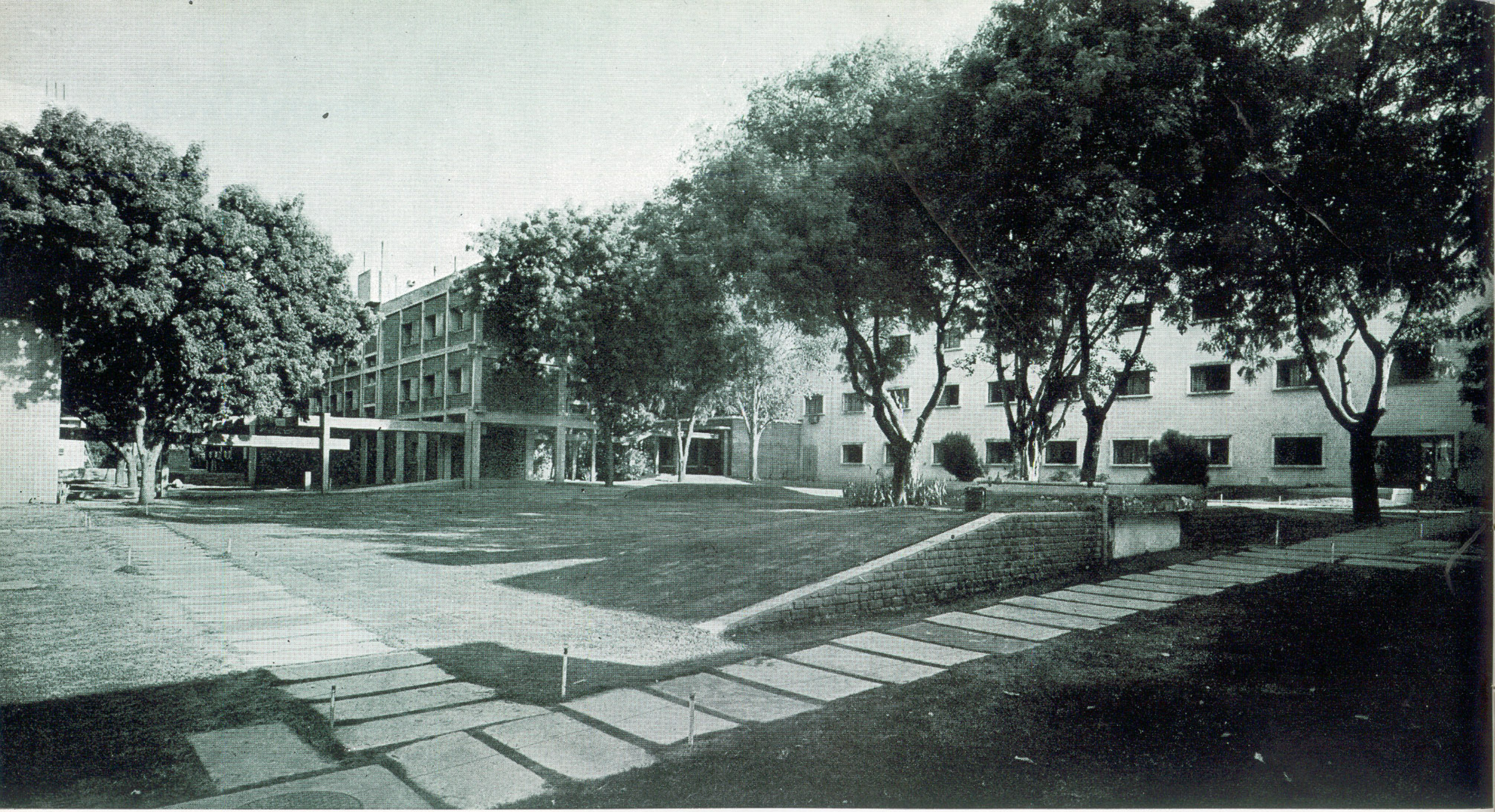
   Worked with the Cosmic Ray group on Solar Wind and Satellite Exploration of Interplanetary Space.

10. **Prof. C. Y. Johnson** (Feb.-March, 1973)

    Lectured, and worked with PRL scientists on Rocket–borne Mass–spectrometry and Extreme Ultra–Violet Detectors.

11. **Prof. J. R. Arnold** (Mar.-June 1973)

    Worked with PRL scientists on Geo–Cosmo–Physics programs.



Inner Quadrangle of PRL

Concluding Remarks

We may conclude with the following quotation from a speech of Dr. Sarabhai, which expresses his philosophy regarding the development of Science and Technology by a developing nation. Addressing the U.N. Conference on the Exploration and Peaceful Uses of Space Science in 1968, as its Scientific Chairman, Vikram Sarabhai stated :

"I believe that several uses of outer space can be of immense benefit to developing nations wishing to advance economically and socially. Indeed without them, it is difficult to see how they can hold their own in a shrinking world .... I suggest that the practical benefits are not realised in full measure unless the applications are undertaken side by side with the serious pursuit of activities which go beyond installing black boxes. They need the investment and commitment of the nationals of the country in related fundamental and applied sciences and innovative tasks...................... We should note that the peaceful uses of outer space as for example in the field of telecommunications, or meteorology, involve developments along advancing frontiers of science and technology. They produce rapid obsolescence not only of hardware, but established systems of organization, of administrators and technicians responsible for producing national services. The full benefits of outer space can be realized only when nationally and internationally an appropriate culture can be created. We could succeed in executing such a programme only when the necessary social change occurs to permit an inter-disciplinary group of specialists and innovators to work completely for a well defined common objective.................

A developing nation following a step-by-step approach towards progress is landed with units of small size, which do not permit the economic deployment of new technologies. I suggest that it is necessary for them to develop competence in advanced technologies and to deploy them for the solution of their own particular problems, not for prestige, but based on sound technical and economic evaluation involving commitment of real resources................ They would discover that there is a totality about the process of development which involves not only advanced technology and hardware, but imaginative planning of supply and consumption centres, of social organisation and management, to leapfrog from a state of backwardness and poverty".

It is in this spirit that PRL and its Faculty have lived, worked and grown during the last quarter century. The small sapling planted by Vikram Sarabhai, has grown into a bunyan tree. Several organisations have had their roots in PRL activities. This laboratory has been the cradle for the space programs of India.

In the fields of research cultivated at the laboratory, it has been an International Centre of excellence, where scientists of many countries have visited, lectured and worked. Scientists from PRL have gone abroad, worked at advanced research centres and returned here, keeping the laboratory always at the forefronts of research in Cosmic Rays, Astronomy, Aeronomy, Nuclear and Plasma Physics.

The future programs of the laboratory will continue and expand the research activities in the fields of Earth and Planetary atmospheres, solar-planetary interactions, astronomy and Geo-Cosmic-Physics, Physics of nuclei and plasmas, with the fervour and dedication that characterised its activities hitherto. The greatest tribute the Laboratory can pay to Dr. Sarabhai will be continuing to contribute to the totality of the nation's developement programs by establishing excellence in all the activities undertaken.

Appendix I

STAFF AS ON 31-3-1973

Dr. Devendra Lal	Director and Professor
Dr. Pandya S. P.	Deputy Director and Professor
Shri Thakore S. R.	Deputy Director and Head, Computer Division
Dr. Ramanathan K. R.	Emeritus Professor
Dr. Pisharoty P. R.	Senior Professor
Dr. Rastogi R. G.	Professor
Dr. Satya Prakash	Professor
Dr. Bhavsar P. D.	Professor (Hon)
Dr. Nerurkar N. W.	Professor (Hon)
Dr. Rao U. R.	Professor (Hon)
Dr. Yash Pal	Professor (Hon)
Dr. Bhatt K. H.	Associate Professor
Dr. Bhonsle R. V.	Associate Professor
Dr. Bimala Buti	Associate Professor
Shri Chitnis E. V.	Associate Professor
Dr. Kane R. P.	Associate Professor
Dr. Kaw P. K.	Associate Professor
Dr. Kulkarni P. V.	Associate Professor
Dr. Parikh J. C.	Associate Professor
Dr. Pratap R. V.	Associate Professor
Dr. Raghava Rao R.	Associate Professor
Dr. Shastry T. S. G.	Associate Professor
Dr. Shirke J. S.	Associate Professor
Dr. Varma R. K.	Associate Professcr
Dr. Abhijit Sen	Fellow
Dr. Agrawal D. P.	Fellow
Dr. Alurkar S. K.	Fellow
Dr. Chowdhury B.	Fellow
Dr. Das A. C.	Fellow
Dr. Degaonkar S. S.	Fellow
Dr. Desai J. N.	Fellow
Dr. Khadkikar S. B.	Fellow
Dr. Razdan H.	Fellow
Dr. Somayajulu B. L. K.	Fellow
Dr. Subbaraya B. H.	Fellow
Dr. Subramanian G.	Fellow
Dr. Sundaram A. K.	Fellow
Dr. Vijay Kumar	Physicist
Dr. Angreji P. D.	Research Associate
Shri Bhattacharya S. K.	Research Associate
Dr. Girija Rajaram	Research Associate
Shri Goswami J. N.	Research Associate
Dr. Gupta S. P.	Research Associate
Shri Gupta S. K.	Research Associate
Dr. Harishchandra	Research Associate
Dr. John P. I.	Research Associate
Dr. Kargathra L. V.	Research Associate
Miss Kusumgar S. L.	Research Associate
Shri Manchanda N. R.	Research Associate
Dr. Rao V. R.	Research Associate
Dr. Saxena Y. C.	Research Associate
Shri Agrawal S. P.	Visiting Scientist

Shri Bujarbarua S.	Visiting Scientist
Shri Shah S. R.	Visiting Scientist
Shri Singhal K. P.	Visiting Scientist
Dr. (Mrs.) Suhasini Rao	Hon. Scientist
Shri Pareekh P. N.	Scientific Officer
Dr. Singh B. P.	Pool Officer
Dr. Dinesh Patel	Chief Programmer
Shri Murty C. S. R.	Statistician
Dr. Rao S. K.	Numerical Analyst
Shri Shah P. S.	Programmer
Shri Basak P. K.	Electronics Engineer SD2
Shri Misra R. N.	Electronics Engineer SD2
Shri Mazumdar H. S.	Electronics Engineer SD2
Shri Parekh N. C.	Electronics Engineer SD2
Dr. Prakash Rao A. S.	Electronics Engineer SD2
Shri Agrawal B. L.	Electronics Engineer SC2
Miss A. Kulshreshtha	Electronics Engineer SC2
Shri Banerjee A.	Electronics Engineer SC2
Shri Banshi Dhar	Electronics Engineer SC2
Shri Das S. R.	Electronics Engineer SC2
Shri Dash B. K.	Electronics Engineer SC2
Shri Goswami K. K.	Electronics Engineer SC2
Shri Goyal A. K.	Electronics Engineer SC2
Shri Jai Bhagawan	Electronics Engineer SC2
Shri Jog N. S.	Electronics Engineer SC2
Shri Karuppaiyan A.	Electronics Engineer SC2
Shri Panchal B. L.	Maintenance Engineer SC2
Shri Patel N. M.	Mechanical Engineer SC2
Shri Ramesh Sharma	Electronics Engineer SC2
Shri Rawat S. D.	Engineer SC2
Shri Seshadri K. S. V.	Electronics Engineer SC2
Shri Sharma N. J. N.	Electronics Engineer SC2
Shri Sharma G. H.	Engineer SC2
Shri Singh R. S.	Electronics Engineer SC2
Shri Sud A. K.	Electronics Engineer SC2
Shri Vyas J. B.	Asst. Administrative Officer
Shri Patel D. H.	Accountant
Shri Natarajan N.	Stores Officer
Shri Desai N. D.	Purchase Officer
Dr. Shah J. K.	Medical Officer
Shri Shah S. C.	Public Relations Officer
Miss Vibha Shodhan	Liaison Scientist
Mrs. Bharucha R. R.	Librarian
Shri D. V. Santoshi	Canteen Manager.

Research Scholars	......	37
Technical Staff	......	257
Administrative Staff	......	87
Auxiliary Staff	...	79
Total Staff	......	566

Indian Academy of Sciences — 34th Annual Session. December 22–24, 1968

Appendix 2

CONFERENCES AND SEMINARS

The Laboratory organised from time to time several Conferences and Seminars. Apart from the presentation and discussion of scientific results, their purpose was to provide an opportunity for the scientists in PRL and other organisations to exchange ideas in informal groups as well as to establish personal contacts. A list of such scientific meetings organised by PRL is given below :

1. Cosmic–ray Symposium. Ahmedabad: March 16–19, 1960
2. Seminar on Space Physics. Ahmedabad: Jan. 28–Feb. 2, 1963
3. Sounding Rocket Experiments and Techniques. Kodaikanal and Trivandrum: Jan. 6–8 and 11–14, 1965
4. International Seminar on Equatorial Aeronomy. Trivandrum: Feb. 3–5, 1968
5. 34th Annual Session of the Indian Academy of Sciences. Ahmedabad: Dec. 22–24, 1968
6. Third International Symposium on Equatorial Aeronomy. Ahmedabad: Feb. 3–8, 1969
7. Seminar on Applications of Atmospheric Sciences for Development in India. Ahmedabad: Aug. 11–12, 1969
8. National Symposium on Equatorial Electrojet. Ahmedabad: Aug. 8, 1970
9. Symposium on Tropical Meteorology. Trivandrum: Jan. 29–30, 1971
10. National Seminar on Indian Programme for Space Research. Ahmedabad: Aug. 7–12, 1972

1973 being the Silver Jubilee year, three Symposia have already been organised and a few more are expected to be arranged during the current year. The Symposia already conducted are :

1. Some problems of Earth and its Environment. Ahmedabad: Feb. 27–March 3, 1973
2. General Many–body Problems. Ahmedabad: March 20–24, 1973
3. Electronic Instrumentation and Communication Techniques. Ahmedabad: July 23–27, 1973

Appendix 3

ROCKET EXPERIMENTS CONDUCTED BY PRL SCIENTISTS

Since the establishment of the Equatorial Rocket Launching Facility at Thumba, nearly 250 rockets carrying scientific payloads have been launched. In early years some payloads were brought by scientists of other countries and were flown in collaboration with Indian scientists from VSSC, PRL or NPL. However, since 1967, majority of the scientific payloads, flown on rockets for sounding equatorial ionosphere, have been designed and fabricated at PRL. The following table lists the various payloads flown on rockets from Thumba by scientists from PRL.

Payload	Exclusively PRL	PRL in collaboration
1. Langmuir Probe	18	4
2. Sodium Vapour	6	7
3. TMA	3	—
4. Proton Magnetometer	10	4
5. Resonance Probe	4	—
6. Capacitance Probe	3	—
7. U.V. detectors	4	2
8. Propagation	2	—
9. Cylindrical Probe (+ve ion)	1	3
10. X–ray Astronomy	8	2
11. Air–glow	1	—
12. Densitometer	2	—
13. Rb–Vapour Magnetometer	—	3
14. Charge particle detector	—	2
15. Electric field probe	—	2
16. Mass Spectrometer	—	6
17. Ba– Sr. Vapour release	—	4
18. Gyro plasma probe	—	1
19. Meteorological	—	119
Total :	62	159

STAFF AS ON 31-3-1973 :

Prof. Devendra Lal
Prof. K.R. Ramanathan
Prof. P.R. Pisharoty
Shri S.R. Thakore
Prof. S.P. Pandya
Prof. R.G. Rastogi
Prof. Satya Prakash
Prof. U.R. Rao
Prof. R. Raghava Rao
Prof. R.P. Kane
Prof. P.V. Kulkarni
Prof. T.S.G. Sastry
Prof. J.S. Shirke
Prof. R.V. Bhonsle
Prof. P.K. Kaw
Prof. R.K. Varma
Prof. K.H. Bhatt
Prof. Bimla Buti
Prof. R.V. Pratap
Prof. J.C. Parikh
Prof. E.V. Chitnis
Dr. S.S. Degaonkar
Dr. J.N. Desai
Dr. B.H. Subbaraya
Dr. Vijay Kumar
Dr. D.P. Agrawal
Dr. B. Chowdhury
Dr. G. Subramanian
Dr. S.K. Alurkar
Dr. B.L.K. Somayajulu
Dr. S.B. Khadkikar
Dr. A.C. Das
Dr. Abhijit Sen
Dr. A.K. Sundaram

Prof. P.D. Bhavsar
Prof. Yash Pal
Prof. N.W. Nerurkar
Dr. H.R. Razdan
Dr. Harish Chandra
Dr. P.D. Angreji
Dr. Girija Rajaram
Dr. S.P. Gupta
Dr. V.R. Rao
Dr. L.V. Kargathra
Dr. P.I. John
Dr. Y.C. Saxena
Shri S.K. Gupta
Shri N.R. Manchanda
Shri K.P. Singhal
Shri S.R. Shah
Mrs. S.R. Rao
Shri S.P. Agrawal
Shri S. Bujarbarua
Shri P.N. Pareekh
Shri V.L. Bhatt
Dr. B.P. Singh
Shri V. Dalal
Miss Nita H. Majmudar
Shri K.N. Iyer
Shri M.R. Sivaraman
Shri P. Sharma
Shri B.G. Rao
Shri M.S. Narayanan
Miss R. Misra
Shri S.N. Pradhan
Shri T.R. Rao
Shri H.S.S. Sinha
Shri P. Muralikrishna

Shri S. Sampath
Shri P.S. Sehra
Shri U.B. Jayanthi
Shri D.P. Sharma
Shri S.M. Bhandari
Shri A.G. Ananth
Shri A.K. Jain
Shri V. Badari Nath
Shri S.K. Mattoo
Shri R.K. Jain
Shri V.H. Kulkarni
Shri N.K. Vyas
Shri B.N. Goswami
Shri M.J. Rao
Shri Y.P.S. Satya
Shri P.K. Chaturvedi
Shri V.H. Gandhi
Shri A.K. Dhar
Shri S.K. Sharma
Shri V. Satyan
Shri R.U. Haq
Shri V.B. Kamble
Dr. G.S. Lakhina
Shri A.S. Sharma
Shri P.N. Guzdar
Shri Bemal Khedkar
Shri P.K. Basak
Shri R.N. Misra
Shri H.S. Mazumdar
Shri A.S. Prakashrao
Shri N.M. Patel
Shri B.L. Panchal
Shri N.C. Parekh
Miss A. Kulshrestha

Shri A. Karuppaiyan
Shri N.S. Jog
Shri Bansi Dhar
Shri K.K. Goswami
Shri B.K. Dash
Shri S.R. Das
Shri B.L. Agrawal
Shri K.S.V. Sheshadri
Shri N.J.N. Sharma
Shri R. Sharma
Shri A.K. Goyal
Shri G.H. Sharma
Shri S.D. Rawat
Shri A. Banerjee
Shri R.S. Singh
Shri Jai Bhagawan
Shri M.B. Angreji
Shri A.J. Shroff
Shri H.O. Vats
Shri B.H. Dave
Shri T.N. Rajaraman
Shri R.K. Swamy
Shri I. Kripalani
Shri K.S.B. Manian
Shri R. Madhavan
Shri J.S. Sindhu
Shri H.S. Sawant
Shri A.D. Bobra
Shri N.S. Nirman
Shri Sohan Lal
Shri S.K. Banerjee
Shri D.P. Devgan
Shri A. Patel
Shri K.G. Sharma

Shri Y.L. Agrawal
Shri R.C. Shah
Shri A.R. Pandian
Shri Mohinder Nath
Shri K.N. Somayazulu
Shri K.V. Pandya
Shri K.D. Patel
Shri G.D. Vyas
Shri S. Saran
Shri H. Chakraborthy
Shri M.E. Latif
Shri P.L. Malhotra
Shri M.S. Phadke
Shri S.G. Tikekar
Shri C.L. Piplapure
Shri A.K. Datta
Shri R. Sridharan
Shri R.V. Krishnamurthy
Shri C.K.V. Achari
Shri P. Venat
Shri B.B. Lal
Shri K.K. Sivsankaran
Shri M.P.K. Kurup
Shri S.R. Naravane
Shri V.K. Parmar
Shri A.D. Rao
Shri V. Babaram
Shri S.V. Kasture
Shri A.R. Gupta
Shri R.T. Patel
Shri P.K. Kikani
Shri R. Rajagopalan
Shri V.J. Parikh
Shri C.S. Kumar

Shri N.M. Vadher
Shri Hatim T. Ali
Shri K.S. Dholakia
Shri R.K. Patwardhan
Shri K.S. Modh
Shri N. Dutt
Shri V.A. Kadam
Shri N.K. Modi
Shri M.G. Phake
Shri C.G. Rathod
Dr. S.K. Rao
Dr. D.M. Patel
Shri P.S. Shah
Dr. D.R. Kulkarni
Miss V.H. Bhatia
Shri Ashok Gupta
Shri C.S.R. Murty
Shri B.A. Patel
Shri H.B. Shah
Shri S.G. Desai
Shri P.M. Chhatrapati
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Shri D.H. Shah
Shri P. Venugopalan
Mrs. V.N. Acharya
Shri P.R. Shah
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Shri P.K. Shah
Shri M.S. Patel
Shri S.K. Shah
Shri U.J. Patel
Shri D.M. Pandya
Shri M.G. Rastogi

Shri N.K. Shah
Miss P.C. Dudhia
Miss S.J. Tharanee
Shri D.H. Shah
Shri A.J. Dosani
Shri P.V. Bhavsar
Shri N.C. Shah
Shri R.K. Mahadkar
Miss M.S. Sharma
Shri C.S. Panchal
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Mrs. M.A. Thomas
Shri M.N. Bhatia
Shri I.K. Kaul
Shri R.I. Patel
Shri J.R. Trivedi
Shri N.R. Shah
Shri R.S. Patel
Shri N.V. Dalal
Miss L.A. Diwan
Shri A.S. Shah
Miss V.R. Kanetkar
Miss Anjana R. Shah
Mrs. Anjana Baxi
Shri S.L. Kayastha
Mrs S.K. Jani
Mrs. B.K. Bhatt
Miss B.M. Shah
Shri K.C. Patel
Shri M.V. Bhavsar
Mrs. S. Bakre
Shri D.K. Patel
Shri H.I. Pandya
Shri K.S. Patel

Mrs. U.K. Modi
Miss H. Shah
Mrs. S.D. Desai
Mrs. M.S. Pandya
Miss R.A. Patel
Shri R.V. Shah
Shri V.R. Chokshi
Shri K.J. Shah
Shri A.H. Desai
Miss C.R. Shah
Shri J.G. Vora
Shri S.C. Shah
Shri G.A. Mecwan
Shri B.V. Mistry
Shri A.C. Dave
Shri H.S. Panchal
Shri S.C. Bhavsar
Shri S.K. Bhavasar
Shri Dhanji Mistri
Shri P.S. Panchal
Shri R.D. Shah
Shri V.M. Thakar
Shri P.K. Gajjar
Shri B.B. Pancholi
Shri J.B. Mistry
Shri J. Mistry
Shri C.L. Gajjar
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Shri N.M. Modashia
Shri H.D. Nagevadia
Shri L.M. Tikhe
Shri V.K. Mistry
Shri P.M. Gajjar
Shri T.V. Panchal
Shri B.N. Charola
Shri J.S. Panchal
Shri S.C. Parmar
Shri K.P. Panchal
Shri H.M. Gajjar
Shri S.K. Lodha
Shri G.H. Patel
Shri S. Bhattacharya
Shri H.N. Chandel
Shri C.G. Yadav
Shri H.K. Chawda
Shri S.V. Chitte
Shri B.K. Patel
Shri M. Kalidas
Shri H.K. Upadhyay
Shri R.K. Suthar
Shri V.C. Tripathi
Shri R.R. Raval
Shri G.S. Sutharia
Shri Shantaram

Shri S.K. Madina
Shri Nagindas Lauva
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Shri P.D. Yadav
Shri B.B. Rajput
Shri K.S. Mahale
Shri N.C. Patel
Shri M.J. Parmar
Shri G.S. Suthar
Shri S. Raman
Shri Kameshwar
Shri P. Singh
Shri H.K. Patel
Shri J.B. Vyas
Shri S.C. Shah
Miss Vibha Shodhan
Shri D.H. Patel
Shri N.D. Desai
Shri N. Natarajan
Shri D.V. Santoshi
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Shri M.S. Patel
Shri A.V. Bagayatkar
Mrs. R.K. Chainani
Shri H.D. Jariwala
Mrs. R.R. Bharucha
Shri C.K. Panchal
Mrs. Urmila A. Ghiya
Miss Swadha A. Majmudar
Shri P.R. Bhatt
Miss Durga Kher
Shri R.C. Bhatt
Shri Yashwant J. Dave
Shri V.M. Shah

Shri V.N. Chudgar
Shri V.N. Patwari
Shri B.T. Desai
Miss N.M. Davierwala
Shri B.A. Maniar
Shri F.A. Pathan
Shri T.A. Bhatt
Shri B.H. Kadia
Shri A.N. Vaidya
Shri Y.F. Cawnporewala
Shri N.K. Shaikh
Shri Valarian Pinto
Shri P. Raghavan
Shri R. Mahadevan
Shri K. Venugopalan
Shri K.P.G. Nair
Shri Ramachandran A.A.
Shri Philip C.S.
Shri C.V. Ashokan
Shri V. Sahadevan
Shri V.C. Mathew
Shri M. Narayanan Kutty
Shri K. Ravi
Shri K.J. Joseph
Shri D. Stephen
Shri M. Ravindran
Shri K. Sashidharan Nair
Shri P.P. Narayanan
Shri R. Sadanandan
Shri T.T. Chacko
Shri K.V. Sudheendranathan
Shri M.V. Joseph
Shri K.G.V. Nair
Shri N.D. Bhavsar

Shri K.T. John
Mrs. P.B. Thakkar
Mrs. U.P. Shah
Shri K.V. Haridas
Shri Y.J. Shah
Miss M. Shah
Shri V.K. Francis
Shri P.R. Patel
Shri I.S. Gandhi
Shri K.K. Patel
Shri J.S. Christian
Miss V.M. Vora
Shri P.T. Langhnojia
Shri P.A. Vadher
Shri N.K. Pathak
Mrs. D.C. Joshi
Shri N.G. Shaikh
Shri M.V. Kapoor
Shri V.R. Patel
Shri J.D. Vasavda
Shri V.R. Shah
Shri D.R. Shelat
Shri A. Somasundaran
Shri D.C. Patel
Shri A.F. Dholakia
Shri J.C. Patel
Shri W.V. Patel
Shri A.N. Pandya
Shri R.P. Rathod
Shri S.J. Gusai
Shri R.C. Raval
Shri A.S. Masavde
Shri D.A. Brahmbhatt
Shri I.M. Patel

Shri I.M. Desai
Shri N.M. Soni
Shri B.H. Brahm Bhatt
Shri N.K. Parmar
Shri M.K. Mandlik
Shri G.P. Patel
Shri G.P. Rathod
Shri K.C. Makwana
Shri R.K. Brahmbhatt
Shri B.V. Prajapati
Shri P.V. Shavle
Shri T.R. Chauhan
Shri K.C. Modi
Shri G.P. Rede
Shri D.M. Makwana
Shri Sudam Brijlal
Shri F.A. Vaidya
Shri K.V. Valand
Shri S.M. Pathan
Shri M.H. Pathan
Shri B. Chhotalal
Shri R.B. Gurkha
Shri R.M. Barber

Shri M.P. Barot
Shri Khilai Mahidin
Shri Ramlal Kori
Shri Ramlakhan Bhaiya
Shri Babau Mali
Shri H. Mali
Shri R. Nahari
Shri R. Barsati
Shri B. Kachkolkhan
Shri R. Dalaji
Shri C.K. Mandlik
Shri C. Patan
Shri G.V. Kori
Shri N.S. Goswami
Shri Hitlal
Shri Jiva Chuna
Shri Manubhai
Shri V.V. Jhala
Shri D.S. Patel
Shri M.H. Vaghela
Shri B. Chimanlal
Shri I.J. Thakker
Shri G. Gomes

Shri M. Thakar
Shri S. Amin
Shri D.S. Patel
Shri Maganlal
Shri T.G. Krishnan
Shri H. Patel
Shri M.J. Parmar
Shri B.P. Patel
Shri P. Gopinathan
Shri R.C. Solanki
Shri H.D. Patel
Shri I.R. Vaghela
Shri K.P. Prajapati
Shri A. Premji
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57	IV	1	Mechanical Engineer SD2	Mechanical Engineer SC2
57	II	27	Maintenance Engineer SD2	Maintenance Engineer SC2

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AUTHOR	TITLE OF THE THESIS	DEGREE (YEAR)	RESEARCH GUIDE
34. P.N. Pathak	"Studies in Cosmic Rays"	1969	V.A. Sarabhai

"It is necessary in creative work to be able to see squirrels and birds."

— *Vikram Sarabhai*