HISTORY OF OPTICAL GLASS AND OPTICAL TECHNOLOGY IN INDIA

A.K.SAXENA and A.VAGISWARI

INDIAN INSTITUTE OF ASTROPHYSICS
KORAMANGALA
BANGALORE 560034

SPONSORED BY
INDIAN NATIONAL SCIENCE ACADEMY
1990

PREFACE

This project was conceived in 1986 and a proposal was put up to Indian National Science Academy in the same year for financial aid for investigation and preparation of the monograph. INSA kindly accepted our proposal and the grants were made available to us in January 1987. We were hoping to finish the work in two years. Unfortunately the research associate Miss. Manjula, left the assignment, after about 18 months and also one of us was away for 6 months on study leave. This caused a delay in publication.

It is an interesting project and we made personal visits to several key institutions, libraries and factories. We also spoke to several leading personalities in the field. We had gained much information through these contacts but in a few occasions we had to spend lot of time and effort to get authentic sources for exact information and dates.

We have made an exhaustive study and we hope that most of the information has been presented here. There can be still some omissions which if brought to our notice we will be glad to incorporate them.

We would like to thank our Director, Prof. J.C. Bhattacharyya for his interest and encouragement to this project and also for permitting us to use the office facilities. We are thankful to Prof. P.Hariharan, Dr.S.Kumar, Dr. S.R. Das, Mr. A.P. Jayarajan, Dr. M.De for granting us personal interviews, to Prof. Hradayanath for a valuable discussion and also Dr.Ram Prasad,NPL, Delhi for being helpful in providing useful information on this subject. We thank the Directors of CSIO and BEL Masilipatam, for their cooperation. Our special thanks to the librarians of Saraswathi Mahal Library, Tanjore; Asiatic Society, Calcutta; Connemera Library, Madras; Survey of India Library, Bangalore; Adyar Theosophical Society Library, Madras; INSA Library Delhi; Madras Presidency College Library, and Physics Department; Proprietors of Veeraswami Naidu & Sons, Tanjore and Purban Industries, Calcutta for their help. We would like to thank Dr. Bag for his good advice and encouragement from time to time.

We would like to express our thanks to Miss M. Manjula for assisting in data collection in the early stages of the project. We would also like to thank Shri. M. Venkatesh for typing the manuscript on the P.C., binding section for binding the volumes to Shri D. Dakshina Murthy for his secretarial help and Ms. L. Christina for proof reading the manuscript.

BANGALORE
Feb. 1990

A.K. SAXENA
A. VAGISWARI

1. Introduction

A. Definition of optical glass and optical technology

Optical Glass is a vital and strategic material for defence, scientific research, surveys, industry and scientific education. Without this key material various instruments like microscopes, telescopes, spectrometers, range finders, cameras, cinematographic projectors and a host of other industrial and scientific instruments would not have come into existence. In short, Optical Glass has extended human vision from the microscopic world to the macroscopic.

Optical Glass is the 'eye' of the modern world. It has been playing a vital role in shaping science and civilization. Its importance in defence and warfare has made the technology of optical glass a closely guarded secret. Today only a few countries in the world produce optical glass, the major producers being the USA, West Germany, Japan, U.K., U.S.S.R., G.D.R., France, Australia, Canada, and India. Of the total quantity of glass produced in the world, optical glass figures only a fraction of a percent though negligible in quantity, overshadows the rest in importance. The value of optical glass lies in its exacting function and the technological perfection required for its production.

The properties which characterise optical glass as a prized material are its high degree of homogeneity, transparency, chemical durability, physical stability, reproducibility and workability. Optical glass differs from ordinary window glass both in its composition and in its freedom from small amounts of impurities that would impart undesirable characteristics. It also requires a very different treatment throughout its manufacture - from the mixing of batch to the preparation of final blank that is put on the grinding machine.

Optical glass can be conveniently divided into different types named after its characteristic constituent. The important types of optical glass are ordinary crown, borosilicate crown, fluor crown, barium crown, ordinary flint, baryta flint, borate glass and phosphate glass. Apart from these, there is a special glass called laser glass discovered in 1961. The size or shape of laser glass can be varied as desired from a fibre to a disc or to a rod. Large size discs and rods of this glass are used for developing nuclear fusion technology to generate atomic energy. Laser glass fibres are used in telecommunication. It is used for making modern sophisticated military equipment and devices. The optical quality of laser glass is superior compared to other optical glasses. The variation in refractive index of laser glass has to be within the range of 10^{-6} as compared to 10^{-4} in other optical glasses.

Glass Ceramic is an inorganic non-porous material containing both glass and crystalline phases. Its development came as a result of the need for large astronomical telescope mirrors. The special characteristics of Glass ceramics are low thermal expansion, temperature stability, high Young's modulus, excellent polishing quality and transparency. Its main application is in the field of reflective optics.

The important intrinsic properties of optical glass are refractive index n_d, mean dispersion $n_F - n_C$, partial dispersion ratios, $\frac{n_d - n_A^1}{n_F - n_C}$, $\frac{n_g - n_F}{n_F - n_C}$ and dispersive power $\frac{n_F - n_C}{n_d - 1}$ or the reciprocal of dispersive power $\frac{n_d - 1}{n_F - n_C}$, v-value, also known as the Abbe value, A^1, C, d, F, and g represent the wavelengths 7682 Å, 6563Å, 5876Å, 4861Å and 4358 Å respectively. Optical glasses are designated by their n_d value and the Abbe value. These properties change easily from batch to batch with small variations in raw materials, temperature of melting, quality of the melting pot and the manner of handling the melt. The refractive index has to be kept within a tolerance of one-tenth of one per cent and the relative optical dispersion (Abbe value) within one per cent for a close match to the optical design and actual fabrication.

Optical technology refers to the art and technical innovations in the field of optics.The term technology is a combination of the Greek word 'techne' meaning 'art'or craft' and 'logos' meaning 'word' or 'speech'.

B Scope of the project and Methodology:

In this monograph a historical account of the development of optical glass and optical technology in India has been compiled.For a clearer picture a brief description of the world account has been included. The report has been divided into two parts.First part contains Optical glass manufacturing and the second part contains optical technology. The section on optical technology covers making of optical components and devices,development in the field of Optical Engineering and use of these optical devices in scientific research,industrial application, surveying , medical and defence requirements & human amenities.

The developments have been traced from the early period to thirty years of the post independent era. The recent development requires a separate exhaustive study.

An exhaustive data collection was undertaken using various methods. First a detailed literature survey was done and the following libraries were consulted: Asiatic Society, Calcutta; Kodaikanal Archives of the Indian Institute of Astrophysics ; Saraswathi Mahal library, Tanjore; Survey of India Library, Bangalore: Indian Institute of Science, NAL

Library, Bangalore: Theosophical Society Library, Adayar, Madras: Connemera Library, Madras State Archives, and the Office of the Ephigraphist, Mysore.

Questionnaires were sent to several organisations to collect data on their activities (a copy of the questionnaires is enclosed in the appendix). Some questionnaires were sent to individuals to ellicit their contribution to the field.A few scientists were also interviewed to get a first hand information on the development of these areas and their views on it.

Finally a number of institutional visits were made to gather data on their working. A trip was made to Calcutta, to CGCRI, NIL, a visit to CSIO Chandigarh, and Andhra Scientific Instruments now known as BEL at Machilipatnam, was also made.

2. Optical Glass : A world perspective

Until the beginning of the nineteenth century, only two types of glass were known – ordinary crown and ordinary flint. The basis of both is a mixture of sodium and potassium silicates, but the former contains lead. With so little variety in the choice of optical glass, it was impossible to satisfy all the conditions of achromatism[1]. The glasses were defective from the optical point of view and it was difficult to find a piece good enough to make a satisfactory lens. In the latter part of the Eighteenth century, a major contribution to improve the quality of glass itself was made by Pierre Louis Guinand of Switzerland[1]. He used a new method of stirring to produce homogeneous flint glass. After many trials Guinand achieved success by cooling the melt very slowly and stirring it continuously. At first, he used a wooden pole as the stirrer, but this mixed the ingredients unequally and caused streaks. In 1805 he used a porous fire clay rod for stirring and discovered that it not only kept the mass thoroughly mixed but also brought bubbles to the surface. Guinand later moved to Germany to take charge of a glass works and there he taught his new method to a young apprentice, Joseph Fraunhofer. Between 1809 and 1813 Guinand – Fraunhofer's important process for melting optical glass in sheets of considerable size was developed and put to test[1]. Fraunhofer made accurate measurements of refractive indices for different colours and found that with flint glass the results depended on the conditions of manufacture. He obtained flint and crown pieces with reduced secondary spectrum but no attempt was made to produce the glasses on a large scale.[1]

Scientists in several countries began to show increasing interest in the glass industry. In 1824 at the instigation of the Royal Society, Michael Faraday in collaboration with Sir John Herschel and G. Dollond, after several years of intensive study succeeded in producing some good glasses by melting glass batches in platinum trays and using platinum rakes for stirring. The resulting glasses gave objectives which were fairly achromatic. In 1834, Rev. William Vernon Harcourt of England in collaboration with Sir George Stokes used new chemical method to investigate various types of glass and as a result of these extensive studies over a period of about a quarter of a century obtained phosphate glasses containning titanium which showed better achromatization.[2]

The next major advance occurred between 1874 and 1891 as a result of collaboration between Otto Schott, a chemist and Ernst Abbe, a Physicist. In 1880, Abbe and Schott aided financially by the Prussian government, began experimenting at Jena with Zeiss, an instrument maker. Their main objective was to develop compositions with which it could be possible to design lens doublets in which chromatic and spherical aberration could be corrected to a much higher degree. Schott made a very wide ranging study of the effects of glass composition on the optical properties introducing components which had not been previously used as compounds of boron, barium, fluorine, phosphorus and other elements. Some elements did not impart new properties and others,made the glass soft or cloudy, but a few were found to impart desirable optical properties to the glass without affecting it. After six years of research, they produced optical glasses in which the dispersion varied with the wavelength in such a manner that something approximating complete achromatism was achieved. This represents the first major scientific study of glass properties.[3]

The association of instrument maker, Physicist and glass maker proved advantageous and by the early 1900s the factory was manufacturing about 80 different optical glasses and had introduced into their mixtures 28 elements not previously used. The Jena organization enjoyed almost a world monopoly for about 30 years, upto the outbreak of First World War, although France and England had started the manufacture some fifty years earlier than Germany.[4]

In 1940 George W. Morey of United States discovered rare earth optical glasses[3]. By introducing rare earth oxides, especially those of lanthanum and thorium into the melt, he obtained optical glasses possessing very high refractive index and low dispersion. The lenses made of rare earth glasses are used in sensitive and special cameras.[4]

During the World War I, the supply of Optical Glass to the Allies was extremely scarce. England and France embarked upon research and produced optical glass while USA with the help of their scientists and engineers succeeded in developing the technology of optical glass in the Country and started its production. Japan also started producing optical glass. The pressure of World War-II compelled Canada and Australia to establish their own optical glass industries. With the supplies cut off from England, India faced a similar problem and a need for indigeneous production was felt. For a detailed account of the world perspective one would like to refer to the paper by AtmaRam(1961)[5].

References:

1,3,4, Maloney,F.J.T. : Glass in the modern world-A study of material's development,Aldus Books, London, 1967.

2. Atma Ram : The making of optical glass in India Its lessons for Industrial Development,Shanti Swaroop Bhatnagar memorial lecture New Delhi. INSA. 1961.

3. Indian Glass Industry and Optical Glass

Indian glass has a respectful history. The use of glass was known in India from Vedic times. Glass (Kāca) is mentioned in Yajurveda (C.1200 B.C.) and in early Sanskrit and Buddhist literature, such as Satapatha Brāhmana and Vinaya Pitaka. In the great epics, Ramayana and Mahabharata there are references to the use of glass and also in other ancient Indian works. (1)

True glass came to be known in India at the beginning of the historical period. In the proto-historic cities of Harappa and Mohenjo-Daro, some vitreous material was found. The Harappans were able to fabricate articles of faience and also to glaze their quartz beads with frit, a material akin to glass. The glass beads discovered at Maski, in Southern Deccan belong to the chalcolithic period datable to the first mellenium B.C. Specimens of glass bangles have been recovered by excavations at Hastinapur and Rupar at a stratum dated 9th to 8th century B.C. At Taxila, glass beads of 7th century B.C. and of the 5th to 4th century B.C. have been unearthed. (2)

The next important phase in the history of ancient Indian glass, is the Mauryan period (313 B.C. - 100 B.C.). Several glass articles of Indian as well as of Foreign origin belonging to Mauryan period were found in the excavations at Taxila and other places.

Satavahana reign (C. 200 B.C. - 200 A.D.) in Deccan marks a definite stage in the history of glass making in India. A number of Satavahana sites have yielded valuable information about the glass having a high percentage of silica content. After the downfall of the Satavahanas,the tradition of making glass was continued by the Ikshvakus in the South-Central India and Kshatrapas on the west coast of India 1.

After the Arab conquest of Sind in the 9th Century A.D. a new era ushered into Indian glass. Several new techniques like glazed pottery, glazed tiles unknown to Indian soil and a new technique in layered bangles were some of the chief contributions made by the new settlers.

Glass articles of finer quality were produced in the Vijayanagara and Bahmani Kingdoms of South-Central India.

Mughal period (1526 A.D. - 1707 A.D) constitutes a very prominent landmark in the history of glass making in India. Many Persian craftsmen were attracted to the Mughal court and under their influence Indian art and architecture took a new form. Some of the best specimens of Mughal glass were made during the regime of Jahangir (1605 A.D.- 1627 A.D.) and Shahjehan (1628 A.D. - 1657 A.D.).(3)

Spectacles made of glass came to be used in India in the first quarter of the 16th Century A.D. On the history of spectacles in India, P.K.[4] Gode has marshalled some evidence regarding the use of this aid. The following evidence from P.K. Gode's article, "Some notes on the invention of spectacles and the history of spectacles in India between A.D. 1500 and 1800" clearly proves the use of spectacles in Vijayanagar about 1500 A.D.

Vyasayogi-Carita, a biography of the great Madhava pontiff Vyasaraya (A.D. 1446 - 1539) composed by Somanath Kavi mentions Upalochanagolak (spectacles with convex eye-glasses) used by Sri Vyasaraya at Sri Krishnadevaraya's court in about 1520 A.D.[4].

As regards the question about the source of the spectacles used by Vyasaraya about 1520 A.D., P.K. Gode suggests that they were perhaps presented to this influential pontiff by the Portuguese along with numerous other presents which are referred to by Somanatha in Vyasayogi-Carita.(4)

Since at that time production of optical glass was not known, people tried to make use of naturally existing crystals for optical purposes. A reference to this is given in the Imperial Gazetteer of India, regarding the manufacture of spctacles from quartz crystals:-

"Vallam Vadakusetti,a town in Tanjore taluka, 7 miles from Tanjore, captured by the British under Joseph Smith in 1771 - The quartz crystals (pebbles) found here are made into spectacles of which the natives think highly".(5)

Prior to the outbreak of the World War I the condition of Indian Glass Industry was not in a good shape. There were only a few glass manufacturing units in the country. Due to the lack of required technology, the quality of the products of the glass manufacturing units was ordinary and the requirements were mostly met by imports. Several committees were appointed by the Government of India to study the position of Glass Industry.

In 1916, the Government appointed the Indian Industrial Commission headed by Sir Thomas Holland. The report of Holland Commission contained observations regarding the responsibility of the State taking the lead and making appropriate provision for the improvement of the glass industry, particularly its technical standards. But no action was taken by the Government on the recommendations of the Commission.(6)

On continued demand of the glass manufacturers, the Government appointed a Tariff Board in 1931 under the Chairmanship of John Matthai, to enquire into the case of glass industry for protection. The Board made a strong case for granting protection to the glass Industry and suggested the establishment of a Glass Technologist's Department as one of the conditions of giving protection. The Board also recommended setting up an organization for research and training at the Harcourt Butler Technological Institute, Kanpur. But Government did not respond to the recommendation of the Board.

In 1934, the Government of India established the Industrial Intelligence and Research Bureau under the Indian Stores Department to act as a clearing house of technical information and for undertaking some investigations to help local industries. In the Bureau's programme, survey of glass raw materials, working out methods of producing some glass decorating materials and helping in the introduction of better glass melting furnaces was also included. Its activities were limited because a very small fund was provided for its research programme.

In 1937, the Uttar Pradesh Government appointed a Glass Technologist to the Government and located his establishment in the Department of Glass Technology of the Banaras Hindu University. However, a full fledged organization for glass research was yet to be established.

The Government of India established the Board of Scientific and Industrial Research (BSIR) in early 1940 at the persuation of Ramaswamy Mudaliar. To make a quick survey of the problems and to mobilise the great potential of the universities particularly of trained persons, the Board appointed several committees.

One of the committees was an exploratory committee for Glass and refractories with the following personnel: C.V.Raman, N.C. Nag, I.D.Varshney, A.Nadel and M.L.Joshi. The attention of the committee was mainly confined to investigations on the production of Optical Glass, purification of glass sands and manufacture of high temperature refractories required for the glass industry. The BSIR in 1941-42 financed a number of research schemes for working out the processes of optical glass production.M.L.Joshi of Lahore had worked on one such project.The Optical glass prepared by M.L. Joshi was subjected to tests at the Mathematical Instruments Office, Calcutta. The specimens examined were found to possess the required dispersion for the use in optical instruments but improvement was necessary as regards the removal of veins.(7)

An editorial(8) on 'Need for a School of glass technology in India' and an article (9) 'The Indian glass Industry' in Science and Culture' (April 1941) revived the attention of the Government to estabilsh a centralised institution for glass research.

A report was submitted to BSIR by M.N. Saha and S.S. Bhatnagar after visiting the BHU with the object of exploring the possibility of organising an Institute of Glass

Research using the University Department. The Board appointed a Central Glass Research Institute committee in March 1942, to advise the Board in this regard with S.S. Bhatnagar as Chairman.

At its First meeting in the Forman Christian College, Lahore, the committee unanimously resolved that the Central Glass Institute should be devoted to research in glass and to the introduction of the industrial processes new to India by technical means. The Institute should include sections of glass technology, glass chemistry, glass physics, furnace construction, refractories,glass engineering, labour control and statistics. The committee recommended bringing experts under the Indo-American co-operation in technical and industrial matters. The committee also suggested bringing the processes of manufacture of safety glass, heat resisting glass, fibre and insulating glass, mechanical stirring of optical glass etc., from USA. In regard to the location of the Institute the committee suggested Calcutta, Delhi, Benaras, a place in UP other than Benaras and Lahore.

The CSIR and the Governing body of CSIR considered the report of the committee in 1943 and decided to name the proposed Institute for glass research as the Central Glass and Silicate Research Institute (CGSRI) and to appoint a Secretary to carry out a survey of raw materials needed for the industry and find out problems in silicate and glass research. The CSIR also appointed a committee with S.S. Bhatnagar as

Chairman for giving guidance and advice to the Secretary.

The Government of India sanctioned a sum of rupees One crore towards the capital expenditure on the establishment of the five National Laboratories including the Central Glass and Silicate Research Institute. A very small amount of 2 Lakhs was sanctioned for CGSRI. Atma Ram was appointed as the Secretary of the committee in 1944. He visited Calcutta, Bahjoi, Bombay, Ceramic section of the Tata Laboratory at Jamshedpur and the Departments of Glass Technology and Ceramics of the Benaras Hindu University. On the basis of the information and impressions gathered during the visits and study of publications on the development of such Institutions in other countires, specially Prof. Turner's extensive writings in the Journal of the 'Society of Glass Technology', Germany and USA, Atma Ram prepared a report for the consideration of the committee. The report set out the position of the industry, its problem, its place in national development, and the need of a research Institute to ensure speedy post-war development of the industry. It also described briefly the standards achieved by the industry in the advanced countries. The functions of the Institute, possible locations, anticipated requirements of staff, equipment, buildings and estimates of expenditure were discussed.

The committee held its meeting in Saha's Cyclotron Laboratory in Calcutta in June 1944 to consider the

Secretary's report. The proposals submitted were accepted unanimously. The proceedings of this committee were considered by the BSIR and the Governing body of the CSIR on August 1, 1944. After discussion of the various points raised on the subject by S.S. Bhatnagar, the BSIR and the Glass and Silicate Research Institute committee in their respective reports, it was decided that the Glass and Silicate Research Institute should be located in Calcutta,adjacent to the Jadavpur College on the Gariahat Road. The name of the Institute was changed from Central Glass and Silicate Research Institute to Central Glass and Ceramic Research Institute (CGCRI) in 1945.(10)

In 1949, Atma Ram submitted to the Government of India a scheme for the production of optical glass, based on the knowledge acquired by him at the experimental optical glass plant of the National Bureau of Standards, USA.

The Government of India approached almost all the optical glass manufacturing firms in Europe and Japan for technical collaboration. As these negotiations failed to secure a foreign collaboration in India, Pandit Jawaharlal Nehru, then Prime Minister of India and President of the CSIR who was very keen on the development of optical glass in the country largely influenced the decision to assign the task of developing and producing optical glass to the Central Glass & Ceramic Research Institute. In the meantime, two senior officers R.D. Sharma and J.C. Banerjee of the Institute were deputed to acquaint themselves with the working of the plant at the Glass Division of National Bureau of Standards. In 1956, the Planning Commission assigned the CGCRI the task of evolving the necessary technology. After about 18 months of systematic work on raw materials and on designing and fabricating of equipment and furnaces, studying details of pot making and , working out different schedules such as stirring and annealing, fixing up suitable compositions, the Institute was able to produce optical glass on a pilot scale in 600 b meltings. The samples were examined by Prof. P.K. Kichlu, Professor of experimental Physics, University of Delhi,in 1958 by the National Physical Laboratory of India, New Delhi and by the Technical Development Establishment (TDE) of the Ministry of Defence, Dehra Dun and were found to be satisfactory. TDE, which is the biggest consumer of optical glass in the country certified the Institute samples as 'A' grade.

On the completion of pilot trials, the Government of India and the Planning Commission reviewed the position with respect to the manufacture of optical glass and early in the year 1960 entrusted its production to the Institute. A plant with sufficient capacity to meet the requirements of the country was fabricated and erected in the Institute premises. It went into production in the latter part of 1960. Since then, different varieties of optical glasses have been developed and are being produced to meet the requirements of the defence establishments and optical instrument manufacturers in the country. It is the tireless efforts and able guidance of Atma Ram that brought successful production of optical glass in the country.

Early investigations at the Institute[11] were confined to the development of borosilicate crowns, hard crowns and light flints. At a later stage, light, medium and dense flints and double extra dense flints were developed. These glasses are required for defence needs like tank periscope prisms, binocular prisms and for achromatic combination in optical lenses, for cameras, telescopes, microscopes etc.

Among the recent developments there are stabilised glasses for radiation shielding windows (SW) and laser glasses. RSW glasses are used for attenuation of harmful high energy radiations in nuclear reactors. These glasses possess the same optical quality as the other types of optical glasses. In addition they are characterised by high lead content and high degree of stability. CGCRI is also involved in the work of developing some new varieties of crown and flint glasses stabilised against gamma radiation, intended for use in imaging systems without transmission losses. Apart from these glasses, CGCRI has developed lead phosphate glass capable of registering tracks due to impingement of heavy nuclei. Since the quantum of requirement of particular variety of optical glass is not large enough, presently optical glasses are being produced by intermittent pot melting process. The continuous melting process is yet to be adopted.

CGCRI has been playing a significant role in attaining self sufficiency in the development and production of optical glasses and ceramic materials.

Apart from fundamental research, one of the functions of the Institute is to transfer the technology and to provide necessary help and assistance for the industry in the improvement of the quality of its products. The industry thus identified is Bharat Ophthalmic glass Limited (BOGL).

BOGL is a Government of India undertaking established with technical help from USSR for the production of Ophthalmic glass (12) It is a part of much bigger deal in which Bhilai Steel Plant was also involved. The reason for establishing BOGL at Durgapur was due to the availability of gas from Durgapur projects at a reasonably low price. The unit went into production in the year 1968 & was the first to produce ophthalmic glass in India. The products initially included white ophthalmic glass blanks and flint buttons for bifocal lenses. Subsequently BOGL with partial technological transfer from CGCRI and partly their own efforts diversified their activities towards optical glasses and other special glasses such as stabilised glasses for protection from gamma radiations, special filter glasses for furnace operation etc., BOGL started its R & D department in the year 1985. This department has since been able to develop stabilised optical glasses used for RSWs, special cobalt blue glass for blast furnace, barium glasses etc.

The article[13] by Kamalesh Ray on Indian know-how and optical glass industry needs a mention in the present context. The views of Kamalesh Ray and our investigations prove that the development of highly specialised technology has been within the competence of Indian artisans, scientists and engineers. The method of indigenous optical glass production in Kamalesh Ray's words should be an eye opener. Certainly the optical instrument making, the system designs including the optical components should go hand-in-hand with optical glass manufacturing. It is also felt that the pace with which our technological developments are taking place in the country, we may require still larger quantities of optical glass in a broad spectrum. The days are not far off when we may have to go for continuous processes of large quantity optical glass manufacturing.

Our description of development of optical glass in India will be incomplete without a mention of Atma Rams work and interest in this field. Most outstanding work by Atma Ram at CGCRI was the establishment of the technology and production of optical glass in the country. He created the necessary infar-structure required for production of country's glass at CGCRI. At the early stages when Indian glass and ceramic industry was still at a rudimentory level. He took up two projects, one was the all India Survey of glass and ceramic raw materials, their availability quantitatively and qualitatively. This helped in establishing the sources of high grade raw material within the country which could be used instead of imported ones. The second project was detailed testing of the products manufactured and marketed by the industry. Atma Ram's work at CGCRI established that India's requirement for optical glass of international standards could be met at CGCRI to a large extent. On the pure scientific side his work on role of Cuprousion in providing ruby red colour is noteworthy. His another important contribution is the production of highly homogeneous optically clear and corrosion resistant lead glass sheets, blocks and slabs for nuclear reactors.14

References

1.	Dikshit,M.G.	:	History of Indian glass University of Bombay, 1969.
2.	Sen,S.N. & Mamata Choudhuri	:	Ancient glass and India, Indian National Science Academy, 1985.
3.	Atma Ram	:	The making of Optical glass in India Its lessons for industrial development CGCRI, Bull. 9, 3,1962.
4.	Gode,P.K.	:	Some notes on the invention of spectacles and the history of spectacles in India Studies in Indian Cultural History,3, 102-12, Poona, 1969.
5		:	Imperial gazetteer of India, vol.13,p.462
6.	Atma Ram,	:	History of CGCRI - Part I: The decision to set it up, CGCRI Bull. 22, 208, 1975.
7.		:	Journal of Scientific and Industrial Research, 1(2),124,1943.
8.		:	Need for a school of glass technology in India.Science and culture, 6,(10),555-58,1941.

9. : A glass technologist 'The Indian glass Industry, Science and Culture,6,(10),559-65,1941.

10. Atma Ram : History of CGCRI Part II:Setting up the Institute.CGCRI Bull.23(2),72-85,1976.

11. Kumar S. : Personal interview with Dr.S.Kumar, Director, Central glass & Ceramic Research Institute.

12. : Reply to the questionnaire from Bharat Ophthalmic glass Limited on the project History of optical technology in India.

13. Ray, Kamlesh : Indian know how and optical glass industry, Science & Culture,31, 511 1965.

14. INSA : Biographical memoirs of fellows of the Indian National Science Academy vol.9. 1984 p 120.

4. Optical Technology - A world account

Early development of optical technology was closely linked with the development of lens and mirror making. Man first discovered some optical uses of accidentally produced lens shaped bodies and later set himself to make lenses[1]. During their evolution from simple magnifying and diminishing glass their use as spectacles, to their combination in telescopes and microscopes and to a still more complex use lenses have transformed same branches of science and virtually created others[2].

The magnifying power of glass spheres filled with water was known to the Greeks and Romans[3]. Some of the optical properties of glass was elucidated by Ptolemy as early as the second century A.D. in his work "Optica". Islamic writers developed the optical conception of the Greeks; foremost among them was AlHasan ibn Alhaythan (965-1039) whose work has a sound experimental basis. He studied the reflective properties of curved mirrors and the magnification of segments of glass spheres and published the results of his experiments[4]. His works were later translated into Latin. These works had a profound effect upon the European Philosophers. Among the western scholars to make original contributions to optical theory was Robert Grosseteste (1175-1253) who first drew attention to the practical usefulness of lenses in making small things appear large and distant objects near[5]. RogerBacon followed Alhasan's experimental trend and conceived of an instrument which served the purpose of a telescope. Bacon also described spectacles which came into use soon. He elucidated the principles of refraction, reflection and spherical aberration[6].

Optical technology as we understand today had its inception in 1286 when the art of optical fabrication was applied to glass for making spectacles or eye glasses for better vision. At first spectacles were provided with convex lenses to aid farsightedness. The lenses were ground to small radius and were comparatively easy to work. No reference to concave lenses for correction of near signtedness or Myopia appears till that of Nicolas of Cusa(1401-64) in the Mid-Fifteenth century[8]. The manner in which the lenses correct the natural defect of the human eye began to be studied in geometrical terms in 16th century. Francesco Mauralico (1494-1575) of Naples showed how the lens of the eye focused light upon the retina and by 1600 Geronimo Fabrifio (1537-1619) had shown that the lens occurs in the front part of the eye ball rather than in the middle as it had been believed earlier.[8].

Following this telescopes were invented. It is generally believed that Hans Lippershey invented the telescope in the year 1608 but this is not certain since telescopes were already on sale in Paris, and in the same year appeared in

Germany, and in various cities of Italy and in London. However Lippershey made number of telescopes and sold them to Netherlands.9

Galileo (1564-1642) reinvented the telescopes using basic optical principles and constructed telescopes for his own use. His largest telescope had an objective 4.4cm in diameter and had a magnifying power of 33. With these simple instruments he unveiled many secrets of our Planetary system and the universe.[10] He got his lenses from Girolama Magagnati of Lendinara (Murano) and also from 'Antonio of Venice'. A lathe was employed for lens grinding and the final product depended to a great degree on the skill of the artist. At this time there were two common methods of preparing the glass blanks for lenses. One was where the foundry would cast glass in plate and lens maker would cut a disk from the most suitable section; or the lens maker would cast the disk in moulds. The glass was cast in pans made of finely ground Venetain rottenstone mixed with egg white calf skins and dried white lead.Pulverised glass was placed in the pans and inserted into a small stone kiln. Francine of (Florence) also supplied lenses for Galileo for 2 decades probably under the supervision of Galileo himself. His lenses were far superior to Galileo's earlier ones from Murano and Venice. Francine built a special lathe for grinding and polishing which permitted greater precision.[11]

Since lenses were used for making the telescopes colour aberration stood in the way of the improvements of the refractors. Spherical aberration was understood but yet no aspherical lenses were made in the 17th Century. Rene Descartes was probably the first man to conjecture that lens surface was the cause of this aberration. In his discourse 'La Dioptrique' published in Paris in 1638 he gives a geometrical construction of lens free from spherical aberration. He suggested two remedies. One to make lenses with elliptical or hyperbolic surfaces which would theoretically be free from aberration, but this was not within the reach of craftsmen of the day. The other and more practical solution was to lengthen the focus of the lens while keeping the same diameter which did not remove but It lessened the aberration.[12]

Further developments were made to manufacturing techniques by Carlo Manzini in 1648, followed by major improvements in production accuracy by Giuseppe Campani in 1660. In 1664, Campani published a book describing several telescopes of extremely long focal length which he had made use of for observations of the planet Saturn. In this work he first revealed his invention of a lathe for grinding and polishing lenses, with this lathe lens blanks cut from glass sheets could be ground directly without previously having been cast in a mold.[14]

In 1650 the Huygens brothers of Holland developed and improved a new method for more accurate grinding of lenses. In 1655 they made a glass of 12-feet focus. The next telescope they made was 23 feet long and had a 21/3 inch objective.[12]

Pere Cherubin D'Orleans published his book 'La Dioptrique Oculaire in 1671 which not only deals with optics, telescopes microscopes their theory and construction and use but also with making of lenses and various machines invented for that purpose to lessen the labour and increase the speed and accuracy of polishing lenses for telescopes. The materials which he used were so nearly like those which are still in use. He gives full particulars for making the moulds turning the tool he invented a practical lathe.[13]

Sir Issac Newton at Cambridge, ground his own lenses for his optical experiments. Around 1666 he proposed a device for figuring hyperbolic lenses. Unfortunately this machine has survived only in the form of a sketch. He was the first to make a succesful reflecting telescope.[14]

The art of optical technology was also applied to making of tiny lenses used in microscopes. The simple one lens microscope was first developed in 15th Century. From then onwards' lenses of increased power were developed culminating in ground lenses of remarkable excellence produced by a Dutch microscopist Antonie van Leeuven Hoek (1632-1723).[15] Then attempts to design a compound microscope to get an enlarged view of the object was made by several people independently. In Netherlands Hans Jansen, his son Zackarias, and Lippershey were some of them.[16]

During 16th Century the use of optical technology in the area of survey and levelling also developed. At the time Plane tables were in use in Europe and only in 1620 portable angle measuring instruments came into use, these were called the topo-graphical instruments or theodolites. This included pivoted arms for sighting and could be used for measuring both horizontal and vertical angles. The micro-meter microscope and telescopic sights were incorporated in theodolites in 1638 and 1669[17] respectively.17.18

During these years experiments began on reflectors. James Gregory drew plans for such an instrument in 1663 but opticians of the day were incapable of grinding a spherical mirror to suit the requirement and so his suggestion fell through.[19]

In the early part of 1723 John Hadley presented a slightly changed Newtonian reflector to the Royal Astronomical Society. It had a 6" paraboloid mirror and a focal length of 625/8 inches and worked better than the 123 ft refractor owned by the Society. Hadley was very helpful in spreading the knowledge of how to make and test the new parabolized mirrors and reflectors which were soon replacing refractors everywhere. In 1733 Chester Hall made an achromatic lens using crown and flint glass but the flint glass of his time was of such poor quality it was impractical to achieve any good quality,[20] twenty five years later aided by a superior flint glass John Dolland was able to patent an achromatic lens.[21] The development of speculum metal made it possible to figure mirrors of larger aperture on a surface that was fairly easy to polish and that remained relatively bright for a considerable time. Such mirrors had the further advantage that they were free from colour and spherical aberration. Sir William Herschel between 1774 and 1789 made a very large telescope using speculum metal. In 1789 the 400 foot (focal length) telescope which was then the largest in the world was installed on the lawn of his observatory Honee, the residence of Sir William Herschel in Slough, England)[22] In 1845 William Parson's telescope with a mirror of six feet diameter and more than 54 feet long tube was the world's largest telescope at that time with the biggest metal mirror ever cast. However speculum metal was impractical for large metal mirrors because it bent easily under its own weight and had to be refigured every few months. So improvement of refractors was sought again and work on good glass for use in achromatic objective was taken up by a swiss craftsman named Pierre Louis Guinand who started work in 1784 and by 1799 produced flawless discs of flint as much as 6 inches in diameter. He moved to Munich and began working with Fraunhofer. Fraunhofer was able to grind lenses excellently and with Guinand he produced efficient lenses. The development of his new technique in the manufacture of glass that yielded large discs of optical glass both crown and flint that permitted the making of large colour corrected objectives seemed to put reflectors in the background again and made modern achromatic telescopes of considerable size to appear.[23]

Ernst Abbe, together with Otto Schott, the glass chemist achieved an entirely new quality of glass melting processes. Otto Schott succeeded in developing glasses that consistently gave the optical properties required by Ernst Abbe. Abbe and Schott introduced many new elements into the glass melt to adapt the glass properties progressively to the optical parameters required by the instrument makers. This glass became a factor of prime importance to the refinement of optical instruments. This achievement made possible not only high-performance optical systems but also the optimum glasses required for them had now been made accessible to scientifically exact computation and commercial production. The reliably high glass quality, a pre-requisite for high imaging performance of an optical system, became one of the pillars supporting the top rank of Zeiss instruments and their reputation worldwide among users in Science, Education and Production.[24]

By the end of 19th century 36 inch (Lick Observatory) and 40 inch (Yerkes Observatory) refractors were produced. They are still the largest refractors in the world. These lenses were made by U.S. firm of Alvan Clarke and Sons. Their optical work was superb, the secret of their success was the remarkable patience during local correction (figuring) to obtain the sharpest possible images at the focus. This technique was better than striving for mathematically true curves because of inhomogenities in the glass.[25]

Carl Zeiss Abbe introduced a whole series of excellent highly corrected lenses which made possible to get highest quality images. These distortion - free lenses allowed full practical realisation of the theoretical resolving power of the optical microscope by the end of the 19th century.[26]

The improved lens designs were conveniently adopted for making cameras for photographic work. The large size press camera and single lens reflex were in use during 1890's. In 1875 the first roll film camera was proposed. The Eastman's Kodak box camera of 1888 with its handy roll of negative paper and with Eastman's widely available processing and printing service gave impetus to the development of amateur photography as a hobby on a mass scale. Numerous small Camera designs existed from the very beginning of photography.

Optical technology in recent years has made remarkable advances. Optical techniques for measuring and specifying optical surface flatness and texture to small dimentions have improved tremendously. Precise methods for determining optical transfer function including electronic image evaluation techniques, have been developed. Novel optical designing approaches including computer-based ray tracing techniques are gaining impetus. The list of such new contributions to the measurements and specification of optical quality is almost endless. On the other hand, a listing of new optical fabrication techniques is somewhat less imposing. Among the first contribution to come to mind is the development of techniques for fabricating precision metal optical components. Solid, large, light-weight metal aspheric mirrors of aluminium and of beryllium often overcoated with electroless nickel (Kanigen), have been made having a finish and figure approaching that previously obtainable only in glass-type sufaces. In addition, investigations have been made to relate the surface texture of metal surfaces to optical behavior and to develop techniques for obtaining fine finishes on metal by mechanical means as well as by electrochemical methods.

Lightweight honeycomb-backed mirrors of fused silica as well as of alumnium and beryllium have been made particularly for extraterrestrial experiments. Emphasis on lightweight optical surfaces capable of high resolution have underlined the importance of specialized mounting techniques and of analytical approaches to mounting structure design for varied thermal environments. Important developments have occurred in the mass reproduction of high-precision optical surfaces by replicating techniques. Small fast, off-axis ellipsoids good to $\frac{1}{2}\lambda$ have been fabricated as well. Refinement of spin casting techniques have permitted the practical moulding of large paraboloids of moderate quality without additional surface operations.[28]

Optical technology played a key role in astronomical observations during 20th century. Large refractors like 36" Lick observatory : Shane telescope (1959) 100" Mt. Wilson observatory Hooker Telescope (1917) and 200" Palomar Observatory Hale telescope were all completed in 1st half of 20th century. The process of coating silver on mirrors by evaporation and subsequently alumnization of telescope mirrors was also developed. John Strong at the California Institute of Technology and R.C. Williams them at Cornell University during 1930's made contributions to this field independently.[27] Development in the area of large telescopes appeared to move toward the application of combined electro-optical systems for the control of large mirrors. New technology Telescopes are being studied.

The proposals for 15-16 Meter class telescope having a large primary mirror made up of individual smaller segments is being thought of. The technology needed for these instruments would be based largely upon the use of an electro-optical sensor to record the image of a star. This stellar image would then be analyzed by a computer to produce electrical signals; these signals in turn, drive servomechanisms that keep the telescope mirrors in alignment and their optical quality in control (such a system is known by the name active and adaptive optics). Proposed ESO 16 m telescope based on this approach has already taken a lead.

Several new products that had been expected to be major items in the consumer market failed to attract the expected attention. The major disappointments were optical videodiscs and direct electro-optical miniature cameras. In the video image area the principal developments included the reduction in size of consumer-level cameras and recorders by the use of established videocassette formats. As a result it appeared that the electro-optical still camera as a replacement for the conventional 35-mm camera was not likely to be a significant entry in the marketplace in the near future. Amateur and home movies on film had virtually disappeared in favor of recording on videocassettes, and it appeared that the applications of electro-optical recording in the consumer area would be reserved for the recording of motion and sound.

In regard to conventional photography the design and fabrication of zoom lenses reached a new level of achievement with the introduction for 35-mm cameras of several zoom lenses that have 5:1 ratios of focal lengths. In addition the use of automatic focus devices in relatively inexpensive cameras became quite a commonplace, with standard electronic sensors and control chips being developed by some manufacturers. The introduction of new high-speed color films gave these cameras additional flexibility. No revolutionary innovations having the impact of Eastman Kodak's Disc cameras occurred recently.

Optical videodiscs virtually disappeared from the market except for specialized educational or catalog applications in which the ability to carry out a rapid search of an image catalog or to interact with a computer-driven educational process is important. Some applications as part of elaborate adventure video games appeared. In these cases scenes selected from a videodisc are mixed with computer-generated action figures that have been inserted in the fore-ground. While this is a sophisticated computer-driven electro-optical system, it is not expected to be sold in large quantities.

The introduction of digital data storage on videodiscs is just beginning, huge volume and rapid access to such data bases are convenient for many applications. Magnetic recording developments made in recent years permitted information storage densities that are competitive with optical storage. However, most authorities believed that optical data storage devices would maintain a tenfold advantage over magnetic in the amount of information that could be stored within a unit area. Major gains in the widespread use of optical data storage were likely to occur as a result of the introduction of erasable reusable media, which in 1984 was just becoming practical.

Optical audiodiscs appeared to be gaining in popularity as the catalog of available selections widened. The cost of players for the discs remained high, and no wide market could be expected until inexpensive portable players appear.

In terms of other applications the laser machine shop is growing. Some of the work being done is obviously experimental, but the production of elaborate detailed structures in materials that cannot be worked in other ways, such as ceramics, seemed certain to produce new concepts in manufacturing. One of the principal advantages of laser working of materials is that the production of the delicate, thin-sectioned components is possible.

The major component of the electro-optical market, is the defense industry. Large quantities of laser trackers, range finders, target designators, and low light-level or night-vision devices are being procured. This has led to a major expansion in engineering areas and some growth in production. Optical fabrication is still an art to some extent, and the economic efficiencies that had been achieved in selected portions of the photographic lens industry had not yet penetrated into precision optics.

Analytical devices employing laser spectroscopy for the identification of minute impurities in various materials became widely used in industry. Several systems featuring a combined pump laser and a tunable dye laser in a single package became available. Such a device can be used to supply coherent laser radiation of a color or wavelength that can be continuously varied over a wide range. These sources make it simple to achieve high-speed spectral scanning of selected volumes of a material. Significant applications in the chemical industry and the improvement of such combustion devices as jet engines are recorded.

A combination of array detectors and microprocessors led to the development of "smart" sensors that have capabilities though limited for analyzing an observed scene as an intrinsic part of the detector process. The future development of such devices has applications in the areas of robotic vision and the classification of objects in a complex field. The significance of this approach to the recording of images is that some level of intelligence can be built into the camera that initially records a scene. It is possible to detect the presence of specific objects and to determine the orientation of simple three-dimensional shapes almost as fast as the image is being collected. More sophisticated discrimination of objects will require larger computers than the microprocessors presently available. But even with a limited discrimination capability these sensors can be used as the primary detectors for robotic systems in manufacturing operations. Reductions in cost and hazards involved in factories can thus be achieved.[28]

The most exciting applications of optical technology that can be expected in the near future are based on the use of intelligent sensors. For example, electro-optical cameras that can make simple decisions concerning the objects observed on the chip that is collecting the image may appear. There will be considerable development of intelligent sensors as robot vision systems for use in industry. Other applications are expected to be increasignly elegant automatic focus devices and image motion trackers.[29]

References

1,3,13,15. Twyman,F. : Prism and lens making London, Adam Hilger 1942.

2,4,5,6,7,8. Singer C. et al. : A history of technology vol III Oxford, Clarendon 1957.

9,10. : The new Encyclopaedia Britannica Macropaedia vol.18,p.197 1984

20,21,25,12. Page,Th,& Page,W. : Telescopes how to make and use them New York,Macmillan Company, 1966, 40-45.

11,14. Bedini,S.A. : Lens making for scientific instrumentation in the 17th.Cent. Applied Optics, 1966 5, p.687.

16. Encyclopaedia Britannica vol.12, p.127, 1984

17,19. Horne,F. : Optical production Technology London, Adam Hilger,1972.

18. Horne,D.F. : Optical instruments and their applications, Bristol,Adam Hilger, 1980.

22. Morey,G.W. : The properties of glass.2nd ed. New York, Reinhold Publ.Corporation 1954.

22,24. Moloney,J.T.: Glass in the modern world: A study of materials development. London, 1967

26. Auerback,F : The Zeiss works and the Carl Zeiss

foundation in Jena, London
W & G. Foyle Ltd - 19.

27. Passachoff,J.: The large optical telescopes, Mercury,9, p.142-143 1980.

28. Larmer,J.W. : Goldstein,E. Some comments upon current optical shop, Applied Optics 5,p.677,1966.

29. Shannon,R. : Optical Engineering in Science and the Future. Chicago, Encyclopaedia Britannica,1985, p.362.

5. Optical Technology in India

A. Early Attempts

It cannot be very clearly established when exactly optical technology made a start in India. There are evidences regarding the use of spectacles as early as 1500 A.D. In the India Office document of A.D. 1616 a reference is made to 'prospective glasses 'sold at Ajmer by the agents of the East India Company. The historical records show that European telescopes were available in India as early as 17th century. In the first quarter of the 17th century, prospective glasses i.e. telescopes were presented to Emperor Jahangir (reigned 1605-27) by Sir Thomas Roe. Thereafter it became a general practice for the Mughal nobility to get telescopes as presents. With the establishment of British rule in India, various optical instruments began to be imported from Europe.[1]

The first use of telescope appears to have been in 1651, barely 40 years after its use by Galileo. An English man named Shakerley who had emigrated to Surat in West India observed transit of Mercury in 1651 and a Comet in 1652 with telescopes.[2]

In the Peshwa Daftar section No. 34, Letter No. 110, dated about A.D. 1738, there is a reference to a telescope used for naval reconnoitring. A Letter No.74, of 19.12.1766 refers to the use of a small telescope used by the Peshwa. And P.D.32, letter No.106 refers to a crude photographic camera bought from the England and letter No. 105 dated 5.4.1773 refers to a telescope.All these references prove the importation of European articles in which lenses were used from A.D. 1600 onwards.3,4

B. Jesuit Missionaries

There are many evidences which throw light on the use of telescopes by the Jesuit missionaries for surveying work.The historical records of survey of India, vol. I compiled by Phillimore refers to the work of these missionaries.Father Antony Monserrate (1536-1600) determined geographical co-ordinates of about hundred positions on his way from Fatehpursikri to Kabul while accompanying Akbar in 1580/81. He was the first foreigner to compile a map of India C. 1590 based on measured routes and astronomical observations.5

Father J. Richaud (1633-1693), well known astronomer came to Pondicherry in 1689, where he set up his 12 ft telescope. On 19th December 1689, a telescope brought from Siam was used for the first time on Indian soil by Father Richaud, to make stellar observations i.e. about 80 years after the invention of telescope by Galileo. Besides carrying on several important astronomical observations, he also taught astronomy at the Jesuit School, then started at Mylapore.[6] Father Jean Venant Bouchet (1655-1732) is reported to have carried out astronomical observations in Pondicherry for the sake of surveying the Peninsula, particularly determining the geographical positions (in 1719) along the Madras coast. The most well-known astronomer - cartographer Boudier (1687-1757), the French Jesuit was invited by Maharaja Jaisingh II in 1734 to take observations at Jaipur. In order to determine the longitude of various places he made observations of the first satellite of Jupiter on 2nd April 1734 at Fatehpur, again at Jaipur on August 15 1734, then solar eclipse of May 3, 1734 at Delhi and lunar eclipse of December 1, 1732, by using a watch, a 17 ft long telescope and an aperture gnomon. Father Tieffenthaller who came to Goa in 1743, devoted himself to the course of geography, keeping a register of all the astronomical positions he observed upto 1785.

Father Wendel was closely associated with Tieffenthaler and they had for several years been the last representatives of the society of Jesuits in India. In 1759, the king of Portugal banished all Jesuits from Portuguese colonies. (7,8)

C. Raja Jai Singh

Evidence regarding the use of telescope by Raja Jai Singh is given in Zij -1-Mahammad Shahi. This is on the basis of a compilation of observations at Mahammad Shahi observatory, Delhi. Explaining the special features of Zij, S.A. Khan Ghori in his article ' Development of Zij literature in India states that it was the first observatory in India that astronomical mission sent by Jai Singh in the year 1728 to Portugal brought with them a telescope made there. After that he got another telescope manufactured by local artisans. Though Jai Singh's primary instruments are non-telescopic, he was aware of the telescope and to some extent, of its potential as well . He had bought one at a cost of Rs. 100 for his personal collection. In his Zij-i Mahammad Shahi,while introducing a chapter "The visibility of Moon", he states, these rules are for naked-eye observations only, although the telescope is now being made in the country. With the telescope he observed the Moon, the planets of Saturn and Jupiter and the Sun 9,10

V.N.Sharma is of the opinion that the telescope was indeed available to Jai Singh and his astronomers and they did use it to some extent at their observatories. Also Jai Singh's statement regarding the shape of Saturn suggests that the telescope was available to him.11

S.M.R. Ansari has given a detailed account of the use of telescope by Jai Singh. Regarding the source from where Jai Singh obtained the telescope, the author is of the opinion that since Jai Singh had developed close contacts with Jesuits in order to familiarize himself with the European astronomy, he sent an emissary of Jesuits and Indian astronomers in 1728-1729 to the then Portuguese King. It is highly probable that a telescope besides other astronomical books should have been presented to Jai Singh by the Jesuits after Circa 1730. He employed the telescope more as a device just for observations rather than as a measuring instrument. This limited use of the telescope by Jai Singh was due to the optical problems and other defects in the refractors of the 18th century. So he built huge masonary instruments at his observatories.12

D. British East India Company and Survey Work

The earliest use of optical instruments in India was for surveying. Historical records of survey of India (4 volumes) compiled by R.H.Phillimore give an account of the instruments used for surveying during the 18th century with a description of their pattern and the manner in which they differed from modern instruments. All these instruments were not made in India which was then under British rule. The company was not supplying the surveying instruments. The officers were expected to provide their own instruments. As the Company servants were the only traders allowed in the country, there were no merchants or shopkeepers to import such articles. The officers who were in need of instruments had to purchase them from England.

The surveying and mapping advanced with the aquisition of territory. Though surveying was started by Rennel in 1765, it was Lambton who laid the foundation of great trigonometrical survey of India (GTS) for a general survey of the whole country, being controlled by astronomical observations and carried out on scientific principles. With the origin of GTS in 1800, various surveying instruments used for the purpose began to be imported from England.

The surveyors were in constant difficulties with the instruments because of their inferior quality. They had no means of getting the repairs done in India. To overcome all these difficulties colonel George Everest, the Surveyor general of India, brought an accomplished instrument maker Mr. Barrow from London with him & established the Mathematical Instruments Office (MIO) in Calcutta, 1830. This marked the first step in the direction of indigenous efferts towards development of optical technology.

Though MIO was established for helping in the work of GTS of India, later the facilities of the workshop were utilised by the other departments of the Government of India. They started the manufacture of survey instruments in India and repaired those which were damaged and kept a stock of serviceable instruments for issue to the survey and other public departments. Figures 1&2 show the building of Mathematical Instruments office and optical machine lens used in the year 1930.

During this time Everest spotted another talented master crafts man Syed Mir Mohisin. He hailed from North Arcot district Madras and belonged to a good family connected with Nawab's of Arcot. In the beginning he learnt to repair and do adjustments in the new instruments used for survey work. Later he developed skill for making new instruments and

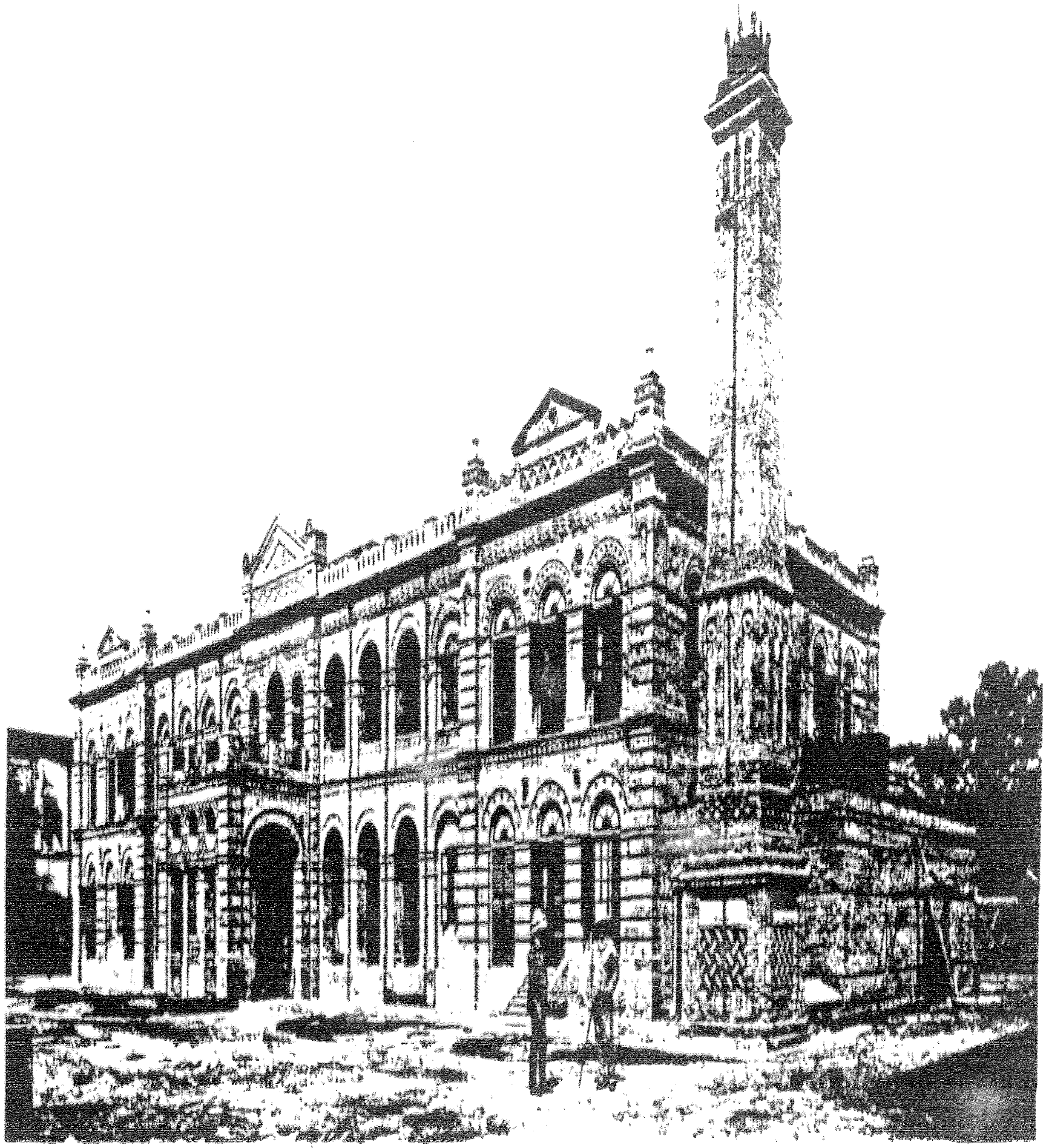


Fig.1. The Mathematical Instrument Office Calcutta

Survey of India Department Built in 1888

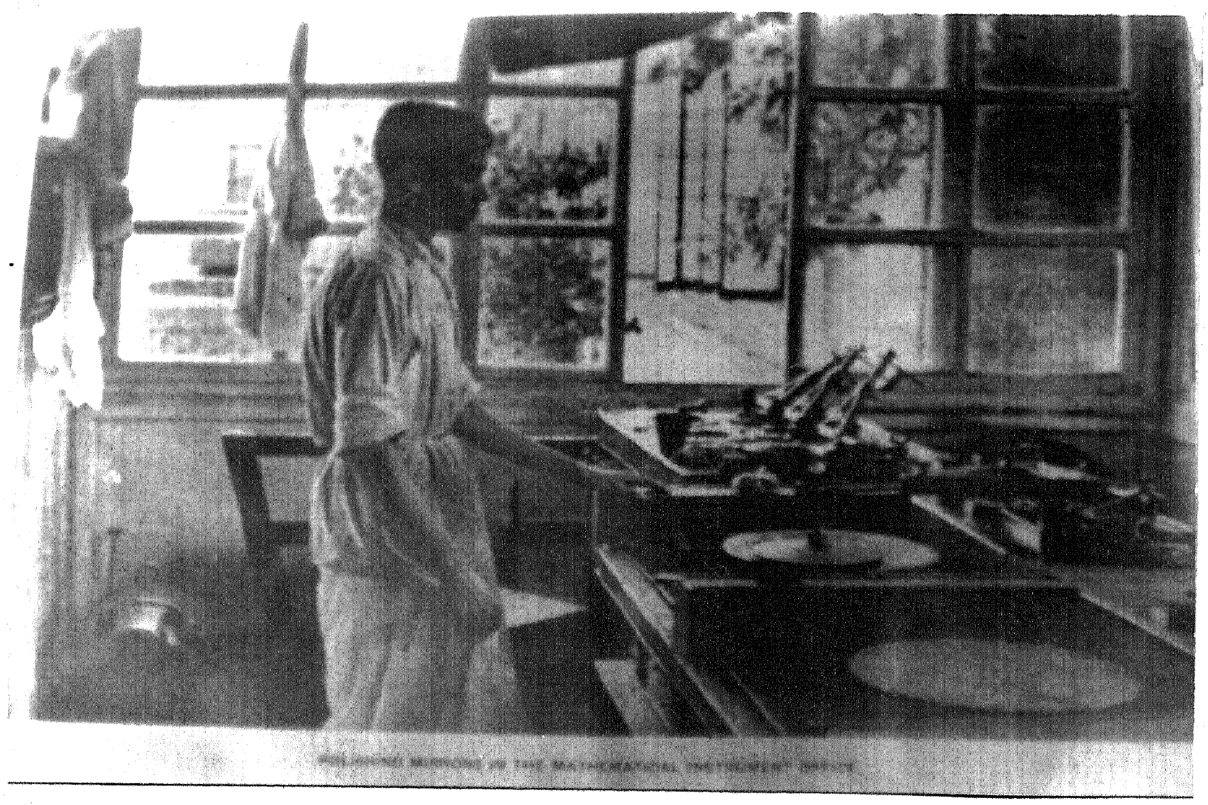


Fig.2. Polishing Mirrors in the Mathematical Instrument Office

remodelling the old ones. In some cases where all the others had failed he was able to set those instruments right and could even improve their performance.Everest thought very high of him,Figs,3 & 4 are examples of his excellent craftmanship.

During the first world war, repairs of optical instruments belonging to defence services were carried out and the office was engaged in the manufacture of compasses, heliographs and other instruments for the Army in India and Messapotamia. A small optical section was started in the year 1919 and for the first time in India processing of manufacture of lenses, prisms and other optical components was developed. The MIO and the ordnance factory at Dehradun which was started during the IInd World War, carried out grinding and polishing of optical components made for sighting telescope, graticules etc., for military use. The know-how and raw materials were imported and local hands were trained in grinding and polishing of lenses and prisms. During the same period surveying instruments like dumpy level and transit theodolite came into production. MIO was later renamed as National Instruments Factory. Since 1957 the NIF is a public sector enterprise under the Ministry of Industry, Department of Public Enterprises, Government of India. In the 70s the factory took a massive diversification programme for manufacturing sophisticated opto-electronic and opto-mechanical instruments. NIF started as a repair unit of the survey of India has how grown into a full-fledged manufacturing unit making sophisticated surveying and defence

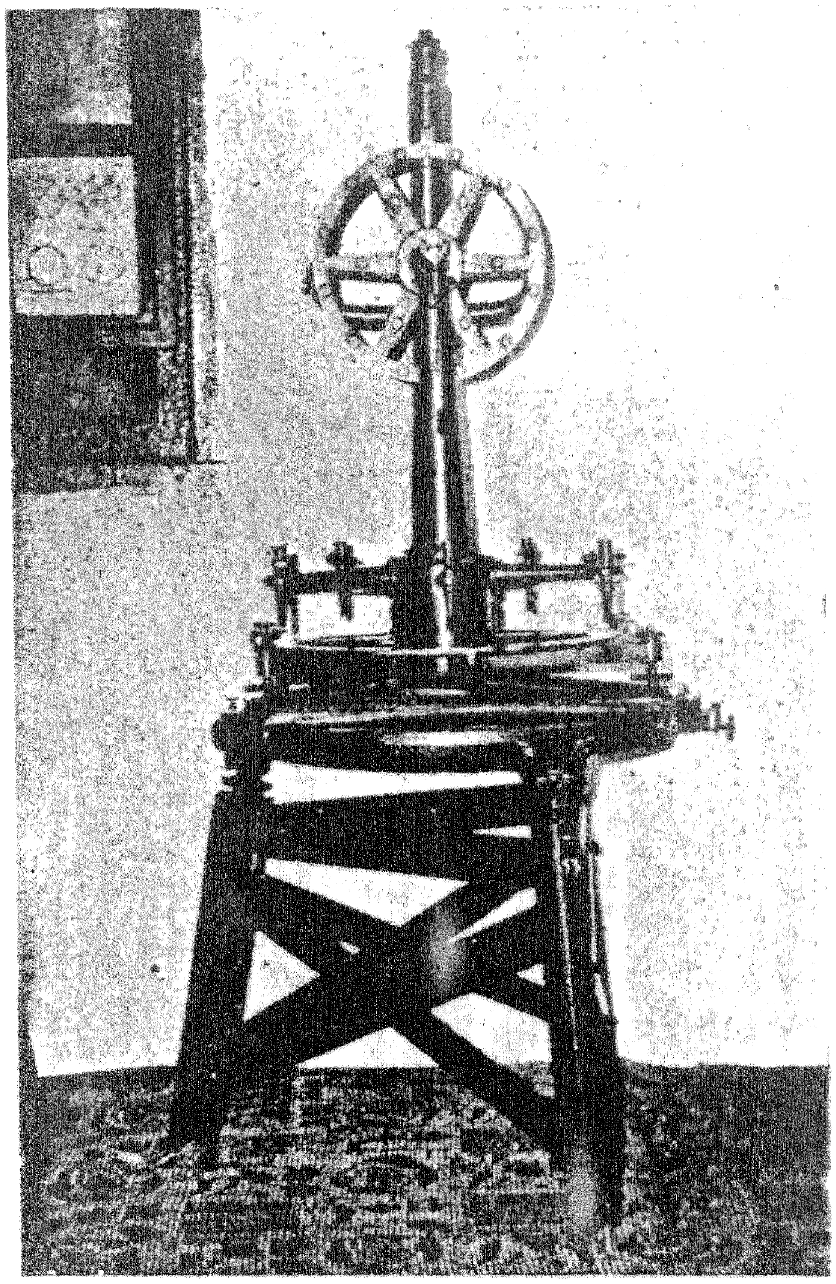


Fig.3. Waughs 24-inch No.1 Theodolite. This instrument was constructed in 1846 at Calcutta under directions from colonel Waugh by Saiyad Mir Mohasin of MIO.

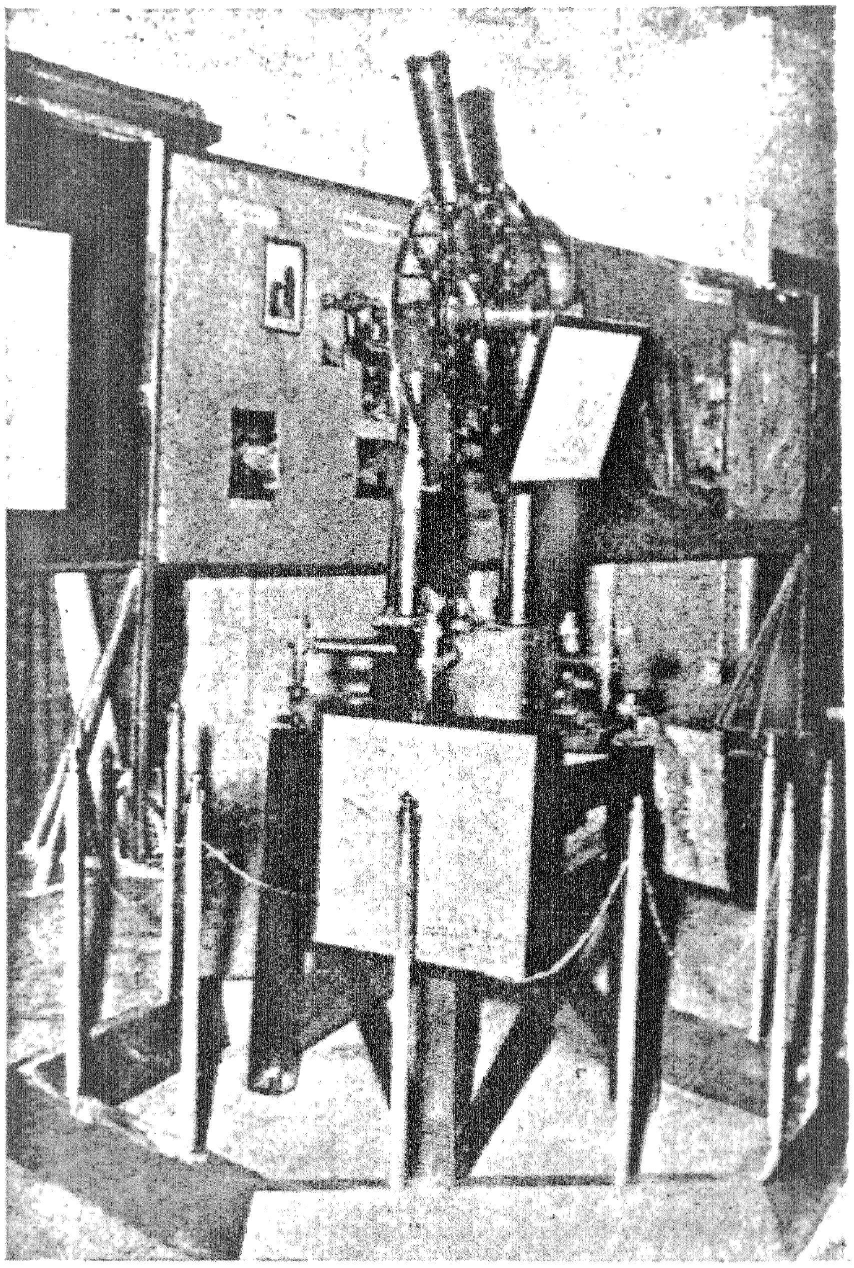


Fig.4. Waugh 24 inch Theodolite No.2. was made in 1847 by Saiyad Mir Mohasin.

instruments in the country.

E. Observatories and use of optical Instruments

With the establishment of observatories by the East India Company and by some Indian Monarchs, various optical instruments were imported into India for making astronomical observations.

The Madras observatory was the centre of astronomical work during the British occupation of India. The observatory was directed by a succession of able astronomers. The Madras series of observations had commenced in 1786 through the efforts of a member of a Madras Government, William Petrie who had in his possession two three-inch achromatic telescopes, two astronomical clocks and an excellent transit instrument. The Directors who were in-charge of the observatory equipped it with new and more powerful instruments and performed valuable astronomical observations.

Calcutta observatory was established in 1825 by the East India Company followimg a proposal by V. Blacker, the surveyor General of India to start an astronomical survey of Bengal in order to supplement the surveying by triangulation method. To begin, with the observatory was equipped with a transit telescope of 5 feet focal length a zenith tube and a Kater's pendulum. Later on a few more instruments namely a transit of 30" focal length, an 18" altitude and azimuth circle and astronomical telescopes of 5 ft and 4 ft focal length were added. At his observatory Blacker, Hodgson and an observer Vincent Rees are said to have done astronomical observations.

The king of Oudh, Nasiruddin Haydar had established an observatory at Lucknow in 1832. The observatory was equipped with a mural circle of 6 feet, a 8 ft transit and an equatorial by Troughton and Simms. In about 1841 Major Wilcox assumed charge of it and made a valuable series of observations with the help of native assistants but after his death the King abolished the observatory in 1849.

The Raja of Travancore Rama Vurma had founded an observatory at Trivandrum in 1837. An Englishman named Caldecott was appointed as the astronomer and equipped the observatory with a transit instrument by Dollond, two mural circles, an equatorial, altitude azimuth, magnetic and meteorological instrument. With the aid of an Indian assistant, Caldecott carried out a great deal of astronomical observations. After his death in 1849, the observatory was in charge of Spershcneider for two years and in 1851 the Rajah of Travancore appointed John Allan Broun as the astronomer. After Broun's departure in 1865, the then Raja of Travancore abolished the observatory.

At Poona a small observatory was established in 1842 by Captain W.S. Jacob. Jacob equipped this observatory with a 5 feet equatorial of Dolland. During 1845-48, he observed the eclipses of Jupiter's satellites to determine the longitude of Poona and also carried our observations of Saturn's rings. He made observations of double stars and compiled a catalogue.

Another observatory was founded at Poona about 1882 by Maharaja Takhtasingji of Bhavanagar. The director of the observatory was an Indian named Kavasji Dadabhai Naegamvala (1857-1912). He equipped the observatory with the following instruments: a 20-inch Grubb reflector, a 6-inch equatorial of Taylor-Cooke, an 8-inch achromatic lens mounted horizontally with a 12" siderostat and solar grating spectroscope, a large stellar spectroscope, a 3-inch transit instrument etc. Naegamvala had been a student of Sir Norman Lockyer at South Kensington and was therefore familiar with Astrophysics. He made observations of the solar chromosphere and the corona at the time of solar eclipse on Jan 22, 1898. Sometimes in 1912, the observaory was dismantled and the instruments were transferred to Kodaikanal Observatory.

Nizamiah observatory was established in 1901 at Hyderabad by Nawab Zafar Jung. The observatory was equipped with a 15-inch Grubb refractor, 8-inch Cooke Astro-graph and a number of other lenses, Clocks and Meteorological equipment. Following the death of Nawab Zafar Jung, the observatory was taken over by the Government in 1907 and was shifted to Begumpet. Now it is the second oldest modern observatory in the country playing a pioneering role in the development of astronomical research in India. (15, 16,17,)

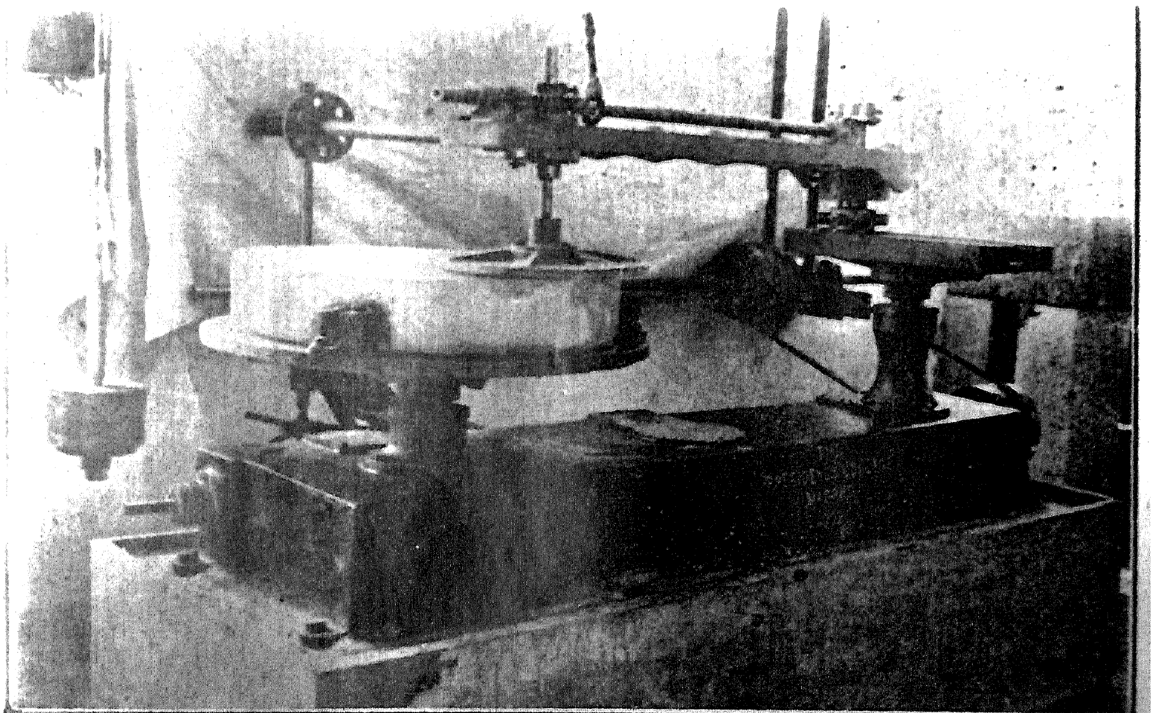
F. Amateur attempts

Astronomical society of India was formed in 1910 by a group of amateur astronomers. H.G.Tomkins was the founder-president of ASI. Even Though Tomkins was a native of England he spent greater part of his life in India. He was very much interested in astronomy. Tomkins was familiar with the process of grinding mirrors for telescopes. He has explained the making of a cheap telescope in the Journal of Astronomical Society of India vol III, 1912-13. p.45 in his paper, Tomkins refers to the availability of materials in India. (The glass discs, emery powder, carborundum and pitch can be had from messrs. Ahmuty and Co., Calcutta). Tomkins applied his natural ingenuity and mechanical skill to the design and construction of a 24-inch reflecting telescope. The greater part of the work including grinding and polishing machine for the figuring of mirror was carried out in India. On his retirement, he completed his work at Dedham, near Colchester.18,19

The amateur astronomers were well acquainted with the process of grinding and polishing mirrors for telescopes. Their work is referred in the early volumes of the journal of Astronomical Society of India.

6. Optical work at Presidency College, Madras

In the early part of the 20th century considerable work was done on optical technology at the Presidency college, Madras by Prof. Parameswaran and his students. Parameswaran had set up a lab to work in high vacuum technique and optics. He started developing techniques for making mirrors and lenses in 1920. C.V. Raman possessed a few of the mirrors made by Parameswaran. By early 30s Parameswaran had an extremely well equipped optical workshop. Later he took up the construction of a big reflecting telescope with 24" mirror. The blank was imported from Chance Bros, U.K. and the fabrication was done at the Presidency College optics workshop. The details of the fabrication of 24" mirror is given by K. Gurumurti in the Presidency College magazine. This work did not progress further, since Parameswaran left Presidency College by the end of 1937. Figure 5 shows the grinding machine specially created for making 24" mirror. In the Indian Journal of Physics vol. 10, 1937, p.205-207 S. Hariharan a student of Presidency College has given more information on work at Presidency College where he has given an account on the making of prisms for optical work. Also he has discussed the performance of a locally made constant deviation prism. Successful methods and techniques were developed to produce prisms of all varieties in the Presidency College. The raw material extra-dense flint-was supplied by Messrs. Chance Brothers, England,U.K. The whole processes of correcting the angles, grrinding, polishing and figuring of surfaces were carried out locally.



THE GRINDING MACHINE SPECIALLY ERECTED FOR MAKING THE 24" MIRROR.
The picture shows the initial process of grinding.

Hariharan has also given details of the Stanley telescope made at Presidency College in the physics association magazine vol. 1, No.2, 1930. (p 80-85) The Stanley telescope was an 8" reflector of the Newtonian type with a parabolic surfaces of focal length about 7 feet. The grinding process was carried out using the grinding machine fabricated at Presidency College.

C.S. Venkateswaran another student of Presidency College has given an account of the Presidency College Workshop in the College physics association magazine vol. II, No. 2, 1932. p.52-56.He has described that the workshop was equipped with a planing machine to produce plane surfaces, glass grinding machine which was capable of giving the rotational and the epicyclic motions required for preparing optical surfaces. A good deal of technical details was developed in the laboratory in connection with glass grinding and new instruments such as the super spherometer was devised to test prepared surfaces. The work in the department also included making of large and small telescope objectives, parabolic and concave mirrors and optical flats. They also succeeded in producing Fabry-Perot etalon and Lummer Cherke plates with a resolving power of 30000. Their performance was found to stand in comparison with the manufacturers. The details are given in the Presidency College Physics Association Magazine, 3 (1), October 1932. (p 44-46) by S. Hariharan.

An astrocamera which was demonstrated in the exhibition held in 1940 was also made in the Presidency College Laboratory.From a personal interview with Prof. Hariharan it was gathered that one Mr. Madhav Rao a private entrepreneurhad developed a plant for coating reflecting surfaces at Madras in 1930. His work was of good quality 20,21,22

H. <u>Private Industry and their contribution to optical technology</u>

In this section we describe briefly the private efforts in the field of optical development in India during 19th and 20th Century (till 1975). The information presented is mainly based on the questionnaires (A copy enclose in appendix) circulated by us during data collection. Many of the concerns, in addition to filling up the questionnaires also supplied us with their brochures. Some information was culled out from these brochures. These have been very useful to us. For information on spectacles made from Vallam crystals, and Andhra Scientific Company a trip was made to the respective places.

Since we did not ask for their sales figures, the amount invested in the R D projects and their budgets,we are unable to gauge how big these concerns are, but the information no doubt gives a sample of the extent of activity in the optical field and the various products which are manufactured by them.

We have described the activities of forteen big, medium and small manufactureres. From the data it is clear that private efforts did not start till after 100 years of government effort when Lawrence & Mayo was established in 1877 and they were the only people in the field until 1930. Second World war seems to have given an impetus to both government and private efforts.

In the private sector, Lawrence and Mayo were the first people to enter the optics field in a big way. They still have a reputation for precision optics and for maintaining a high standard. Lawrence and Mayo was established way back in 1877 with their head quarters in Bombay. In the early days they marketed mostly survey and meteorological instruments and microscopes. These were to a large extent manufactured in UK and was sold in India.

During the years prior to the out break of second World war they started manufacture of survey instruments in collaboration with E.R. Watts. Dumpy and high way levels which they manufactured were the earliest levels that were made in India. They also manufactured magnifiers for Diamond Industry,in Surat, and pick-counters for textile Industries. During the World War II they manufactured Goggles for defence purposes. In addition they made singles for bifocals and were the first to undertake lens grinding in India.

In the Madras District Gazetteer, 1906 a reference is found as follows:Near Vallam are found certain quartz products, which are known as Vallam stones. They are probably derived in the first place from large quartz veins in the metanophic rocks. The principal varieties are the pellucid or rock crystal, the dark-brown or smoky quartz, the yellow or cairngorm the amethyst. These are cut by the lapidaries at Tanjore, Kumbakonam & Vallam into a variety of ornamental & useful articles.The white varieties are made into spectacles which sell throughout the Presidency.

A personal interview with Sri Govinda Rajan of T.K.V.Naidu & sons, highlighted the work of Late Shri T.K.V. Naidu, founder of T.K.V. Naidu & Bros, Scientific opticians & optometrists, manufacturers of Vallam pebble optical lenses since 1892.He was making spectacles using vallam stones. They claim to be the first in south to have had started spectacles making. Their vallam pebble lenses were supplied to Sir. C.V. Raman & S.C.Bose. (See Figures 6 and 7) Due to unavailability of crystals at vallam they have stopped making pebble optical lenses since 1950.

Messrs S.K. Dhar & Brothers of Hoogli were manufacturing telescopes in the early part of this century. A Newtonian reflector with 4-inch mirror made by Messrs. S.K. Dhar & Bros.,was used by Nagendra Nath Dhar for making observations of Lunar eclipse, of Nov. 17th 1910. (The Journal of Astronomical Society of India vol. 1, 1910-11 p.23) Another

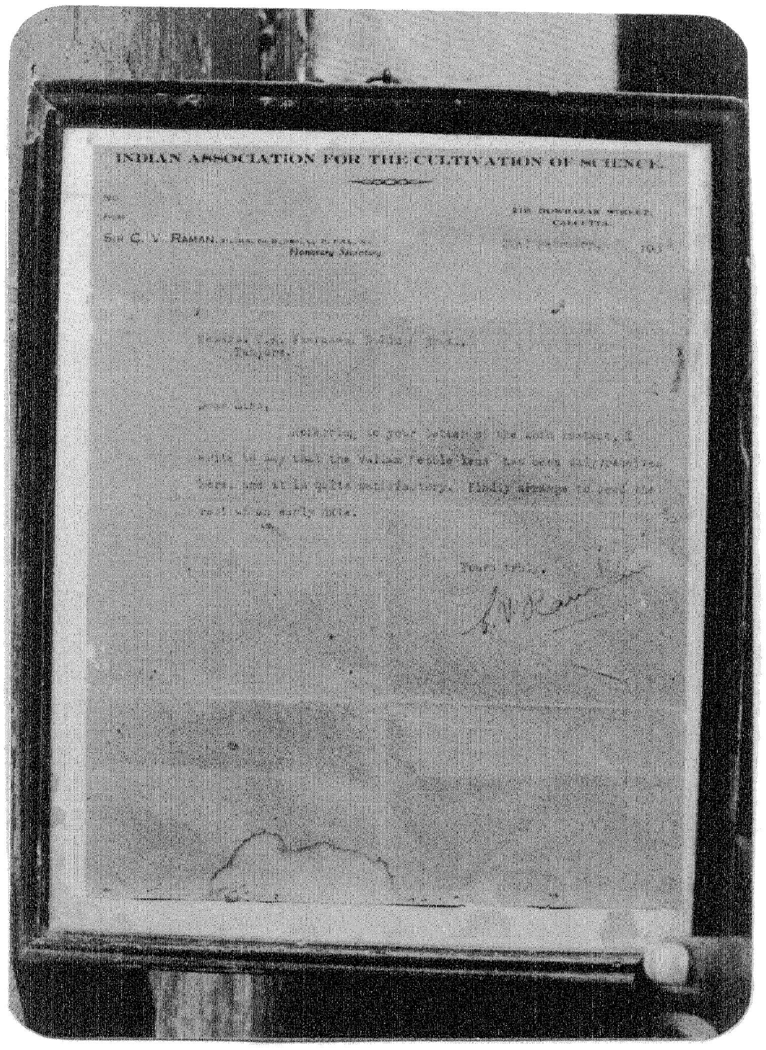


Fig.6. Letter of appreciation from Prof. C.V. Raman to Messers Veeraswami Naidu. Tanjore. (Courtesy Veeraswami Naidu & Sons)

evidence in this regard is the paper on the testing of parabolic mirrors by Dr. E.P. Harrison which he begins with the following paragraph.

"Messrs.S.K. Dhar & Bros., of Hoogli, who manufacture mirrors for reflecting telescopes, have lent me the mirror which is exhibited this evening. It was tested by Babu Nagendra Nath Chatterji and myself in the physical laboratory at Presidency College and the tests indicate that the figure of the mirror is excellent. The work of grinding and polishing seems to be very creditable for a local manufacturer".

In 1926 with no resources but a few hundreds of borrowed money from his friends and no assets but his activities and faith in his capacity, Sri Ayyagari Ramamurthy a science teacher from Andhra started the Andhra Scientific Company in 1926 as a trading cum manufacturing unit. The first ten years were challenging. With courage and devotion he built up the business and brought it up from almost a one-man-show into a considerable size and importance. In 1937,he converted it into a public limited company with capital of Rs. 5 lakhs. The second world war gave a boost to indigenous production and the Andhra Scientific Comapany, which was already well equipped for it, seized the opportunity. Ramamurthy spotted and recruited right talent and started a research and development department, which enabled him to go into designing and production of advanced and sophisticated optical instruments.

Fog.7. A news item in the local paper in the year 1932 paying tributes to Shri. Veeraswami Naidu for his contribution to spectacles and optical component making. (Courtesy Veeraswami Naidu & Sons)

done in 1950. In 1976 large aperture parabolic reflectors for Defence was developed. Advanced technologies in fabrication of optical components like roof prism, pentagonal prisms, rhomboids & high-power microscopes, were also developed. The company merged with BEL in 1983.

When Mr. Ramamurthy had established Andhra Scientific Co, in Andhra, P.C.Banerjee ventured to make optical components & instruments in Bengal. He was the founder proprietor of Purban Pvt. Ltd at 37, Dharmatala Sreet Calcutta. They were manufacturing student microscopes, dumpy level and quick-setting precision levels etc. After the death of P.C. Banerjee the company could not function properly due to some family disputes. Later the company was taken over by a society run by workers. When authors visited the place in January 1987 it was functioning with a few skeleton staff and machines. Couple of workers were seen grinding and polishing small lenses.

According to our sample, next important concern was the Indian Emporium which was established 1941, at Roorkee (U.P.) They manufacture surveying drawing and mathematical instruments. They specialised in Transit and Optical Pummet theodolites dumpy levels, box sextant, optical squares, prism squares, line angers and pocket and mirror sterescopes. Following this was the Jyothi limited of Baroda which was started in 1943. It was not initially in the field of optics but started specialising in optics later. Recently they have diverted their efforts to laser optics and offer laser alignment systems.

Ambala town in Punjab has always been a centre for improving and manufacturing various engineering components. Jaisons & sons of Ambala have been producing Opto-Mechanical and electrical instruments for educational, Research and defence applications since 1949. Budh Singh and sons at Roorkee have been in the business since 1952. They are well known for manufacture of optical and - mechanical equipments for civil engineering and defence. They still manufacture lenses for surveying and other scientific equipment. They have a R.& D. Department which is trying to develop new techniques in instruments for surveying and engineering. Optical Instrumentation in Delhi is another manufacturer of Ophthalmic instruments,& components for scientific and Optical instruments. They manufacture Facimeters, retniscopes and telescopes. Optical engineering Laboratories is another private effort in this locale. They have concentrated on crystal optics and associated instrument manufacturing. Electrofones Science House, Ambala was established in 1959 for manufacturing scientific (Optical) instruments for schools and colleges, they specialise in instruments like spectrometers, travelling microscopes, telescopes, optical benches, etc., Towa Optics of Delhi, which has a collaboration with Towa-Japan since 1962, manufacure microscope eye pieces, and objectives and other optical and scientific lenses. Around the year 1965 Dr. P.K. Kichlu after his retirement had started

M/s Optical instruments Co with its office and workshop at Connaught place, New Delhi. They were manufacturing different kinds of optical components including polarisation optics like Wollaston prisms etc. One of the authors had an opportunity to visit his organisation in the year 1971 and had seen Dr. Kichlu himself working with other co-workers. He was undertaking specific requirements only. After his death in 1982 the company was sold to another partner. No information could be obtained on the present status of the company.

M/s Precision optics and machineries (P) Ltd., Calcutta had started making optical components and devices in the year 1967 & their growth has been steady but slow. M/s Harvin optical and glass industries and their sister concern M/s Scientific Engineering house Pvt Ltd established in 1967 have been manufacturing optical components and instruments for defence use and various research organisations in the country. They claim to be the first in India to supply night vision binoculars to our defence ministries.

Universal Optics, Roorkee established in 1965, is engaged in fabrication of precision Optics for many government departments like Ministry of Defence, ordnance factories; IRDE Dehra Dun; Keltron etc. Opticolite industries, New Delhi which was started 1967 is concentrating on laboratory Optics. They make precision optical components from optical glass and quartz. Some of their products are exported to Australia, Singapore, Malaysia, USA and UK. Vacuum instruments company from New Delhi, though not engaged in optical work directly make vaccum coaters for optical components. Spectra systems also manufacture precision optical components and related systems. It meets the requirements of industry, R & D Units, space and education departments. They also make optical flats and parallels, optical windows, prism and prism combinations, optical wedges and polygons and beamsplitters & also lenses and precision optical cells. Spectra Lase of New Delhi specialises in Laser optics. They manufacture lasers, holographic equipment, vacuum coating both for scientific & commerical purposes. Tej optical works in Hoshiarpur U.P.,manufacture wide angle lens systems. They started in 1973. Ajay scientific Industries manufacture graticules of all types. It is a sister concern of Scientific India, Ambala.

I. Telescope making in India

Considering the importance of telescopes in the field of optical technology, this section gives a brief account of the telescopes in India with their associated instrumentation.

The biggest solar telescope available in the country is the Kodaikanal Solar tunnel telescope installed in 1959. This is of fixed-tube type fed by a 3 mirror coelostat system. The optics is mounted on isolated concrete platforms in an underground tunnel, which also houses a long solar spectrograph. The spectrograph can produce extreme high dispersions with high resolution; a typical value of 10mm per

Å with a resolving power of a few times 10^5. The lens for the telescope was supplied by Hilger & Co and the grating from Bausch and Lomb which was later replaced by Babcock grating received on loan from Mt. Wilson and Palomar Observatory. Both the Coelostat mounting and optics as well as the image forming objective were manufactured by Grubb Parsons, U.K. A Pointing tube coronograph, with a specially selected single lens having extremely low scattering properties was put into operation at Kodaikanal. The instrument has been sparingly used due to some technical reasons. Another Solar observing facility is at the UP State Observatory, Nainital which uses a locally fabricated 46 cm coelostat and an imaging telescope. The Udaipur Solar Observatory surrounded by the waters of the lake for good seeing works with a 12 feet Spar Telescope.

The oldest night telescope in the country, still in use, is the Madras 8 inch equatorial now installed at the Kodaikanal Observatory. It has refracting optics obtained from M/s. Troughton and Simms of England in 1865. At present, it has a photoelectric photometer at its focus, and has been mainly employed for photometry of variable stars and comets.

The next oldest telescope in use is a Grubb-Parsons Cassegrain telescope of 52 cm aperture. This was employed in photometric and spectroscopic observations at Kodaikanal until 1978, when it was shifted to Kāvalur. The telescope was originally obtained by Prof. K.D. Naegamvala in 1890s for Poona Observatory, and subsequently transferred to Kodaikanal in 1912. Another old telescope still in use is the 38 cm (15in) Grubb refractor of the Nizamiah Observatory at Begumpet, Hyderabad. In recent times considerable work in photoelectric photometry has been done with this telescope. Owing to deterioration of environmental conditions, observational work with this telescope has remained suspended over the past few years, and plans are afoot to shift it to a new location in the Osmania University Campus.The old 8" Cooke astrograph with a 10" guide telescope used in the international Carte du Ciel program (1912-1934) is now installed at the Japal-Rangapur Observatory of the Osmania University.

At the time of starting the UP state Observatory in the year 1950 a few telescopes were imported, largest of them being a 52 cm reflector made by Cox Hargreaves and Thomson of UK. Others are 15 cm f/ 15 reflector (Cooke), 25 cm f/15 refractor (Cooke) and 38 cm, f/15 reflector.

In the late 1960s three optical telescopes of larger than one metre aperture were purchased from foreign manufacturers and installed in three observatories. These are: 122 cm reflector at Japal-Rangapur Observatory,104 cm reflector at UP State Observatory,and 102 cm reflector at Kavalur Observatory, the 122 cm telescope was manufactured by J.W. Fecker & Co, USA, and has a Nasmyth focus, and provisions for a wide field Baker corrector and a Coude focus. The other two telescopes are made by M/s. Carl-Zeiss, Jena of German Democratic

Republic, and are both called as 'One metre telescopes'. The aperture sizes notified by the two observatories, are decided according to their own criteria, although the two telescopes are identical except for slight differences in mounting to suit different latitudes at the two sites. Both the telescopes have f/13 Ritchey-Chretien foci and f/30 coude foci, with several optical attachments which considerably augment their capabilities.

Punjabi University, Patiala obtained a 60 cm aperture Carl-Zeiss Cassegrain reflector in mid-seventies; after some delay the telescope has now been installed in a dome in the university campus.

When demands for observational time on telescopes grew, and the existing observatories could not meet all demands, several scientific groups imported portable 14" telescopes from abroad. These are almost invariably of Celestron 14 model, which has partially hybrid optics in Schmidt Cassegrain combination. Three very active groups who resorted to this scheme are (i) the Physical Research Laboratory working at Gurusikhar, (ii) The Positional Astronomy Centre, Calcutta, with temporary observatories away from the city and (iii) The ISRO Satellite group at Bangalore. In recent years, They have carried out, in recent years, very interesting observations using these modest aperture telescopes.

Efforts to fabricate astronomical telescopes in India can be traced back to the early years of this century, when S.K. Dhar and Brothers of Hoogly started making small reflectors. Many other small entrepreneurs and amateur groups made valiant efforts to rig up a respectable size telescope in later years. Largest mirror for such a project was a 24" paraboloid which was started by H.P. Waran of Madras, but could not be completed due to lack of funds. A detailed account is given in an earlier section.

Concerted efforts to design and fabricate astronomical telescopes were started in several institutions after independence. One such endeavour was by P.K. Kichlu of Delhi university in late fifties; his efforts were ultimately taken over by a company who produced several small telescopes. But more determined efforts were channelled by M.K.V. Bappu (at Kodaikanal) who employed greater resources he could command as the Director of the Observatory in developing indigenous telescope making capabilities. A.P. Jayarajan took up the challenge of developing optical shop facilities, and their first telescope a 20 cm Schmidt with 15 cm corrector plate was put into use in 1965. This was followed by a 38 cm Cassegrain telescope, whose optics was completed and fitted on an old telescope mount available at Kodaikanal. This telescope is being used regularly at the Vainu Bappu Observatory, Kavalur ever since 1968.

The project taken up by the Kodaikanal team was a 76 cm Cassegrain telescope in the early seventies. In this venture, the entire telescope complete with the mount and drive was planned to be fabricated. The fabrication of the mount and optics posed unforeseen problems. Ultimately a modified design was finally successful in 1980, and the telescope was employed in an occultation experiment in April 1981.Still many problems, connected with figure of the mirror blacklash in the gear system, erratic drive, distortion due to stresses in the mirror cell, etc, remained which were removed one by one. The mirror was refigured and secondary of the mirror has been replaced. The telescope was equipped with a modern electronic drive and coordinate display system, and is being used for regular observations from 1986.

In the mid-sixties, the UP State Observatory imported the optics and tube for a 56 cm reflector telescope, amd made the mounting and drive assembly for the same in the observatory's workshops. This appears to be the first major mount and drive fabricated in the country, The first complete optical telescope with Optics, mounting drive dome and building was done by the scientists and engineers of Indian Institute of Astrophysics in 1980, when the 76 cm Cassegrain telescope became operational at Kavalur.

Besides these two institutions engaged in researches in astronomy and astrophysics, the activity of telescope making has been taken over by a few small entrepreneurs in India.

among them, two firms appear very active as judged from their advertisement and exhibits. They are M/s. P. Devadas of Madras and M/s. Tejraj & Sons of Bombay. They have successfully produced reflecting telescopes complete in all respects and supplied these instruments to some scientific and educational institutions.

The number of astronomical telescopes completed in India is not large, but the figure does not reflect the capability in the country for producing good optics. Many large reflecting surfaces were completed for special scientific instrumentation. Large collimators and camera mirrors have been produced and incorporated in spectrographs; Optics for high precision laboratory testings have been prepared and any reasonable demand for accuracy can be met with our existing methods and techniques.

The Vainu Bappu Telescope the present largest optical telescope in the country with its 2.34 cm primary mirror. was conceptually planned in the year 1945-46 with a mirror of 100" dia. It was only in 1973 when green signal for the telescope came through. It was then the work of building such a telescope had started A detailed report on the telescope project has been published by Prof. J.C.Bhattacharyya.[23]

J. Development of optical technology at Govt. Institutions

We have compiled here the work in various government institutions and departments based on the replies received from respective organisations. In an earlier section the work of NIL and survey of India has already been given. The ordnance factories (Est 1943) which come under Ministry of defence, Govt.of India work under the Ordnance Factory Board. There are several of them but only two of them produce optical instruments: They are the Ordnance Factory in Raipur, Dehra Dun, and Opto Electronics factory also in Dehra Dun. The one in Raipur, was established way back in 1943 for production of sighting and ranging instruments for Defence.

National Physical Laboratory, New Delhi, organised its activities in Optics as a part of its institutional structure right from the start in 1950. Dr P.K. Kichlu became its Director around 1964. At that time it was hoped that Optics would become a major thrust area of NPL. But unfortunately Dr. Kichlu left soon after. NPL however added a new dimension by starting work on design and development of optical systems and some interferometric techniques. In recent times they have established facilities for thin film coatings.

Telecom Research Centre (TRC)in New Delhi also a Government of India enterprise, works for the Posts and Telegraphs department. TRC has been engaged in design and development of telecommunication equipment. One of the projects taken up in recent past is the introduction of optical fibre in communication.

The Central Scientific Instruments Organisation was established is 1959. CSIO in a national laboratory engaged in research, design and development of instruments pertaining to various disciplines of science and technology. Applied Optics is one of the major activities of the Organisation. In addition to headquarters located at Chandigarh, the organisation has several service and maintenance centres at Bombay, Calcutta, Cochin, Delhi, Hyderabad, Jaipur, Lucknow and Madras. However, R & D activities in optics are confined to Chandigarh only. Some of the R&D projects are taken in collaboration with other research institutes in the country, like Indian Space Research Oganisation, who are the current collaborators for the development of space optics.

The development of radial master metrological grating engine was carried out in collaboration with Australian Development Assitance Bureau, Sydney, Australia.The present R&D activities are mostly confined to space optics, TV projection lens and long linear metrological gratings.CSIO has a strong base of optical design engaged in sophisticated optical modules /system design. Computer facilities are also available.

Facilities exist for the replication of conventional graticules. A radial master grating generating engine, developed at CSIO, provides the facility of making master radial grating for suitable metrological applications.Prediction optical components are fabricated in CSIO. Reflecting surfaces upto a diameter of 300 mm and refracting surfaces upto 125 mm can be processed to the accuracy range of $\lambda/4$ - $\lambda/10$. Single layer AR coating, protective alumination, silvering, are routinely done. Multilayer interference filters and beam splitters, circularly variable neutral density filters and cold mirror have also been developed.Optical testing facilities include all parameters' tests and basic geometrical optical performance evaluation tests for optical elements/lens system.

Instruments Research and Development Establishment Dehra Dun is a leading defence organization in optical techonolgy established in 1960. It caters to the needs of the defence.They design and develop various types of optical, electro-optical, optronic, servo, fibre optic and holography based instrumentation and carry out investigations on major defects on existing instruments and suggest solutions thereof. They also prepare manufacturing particulars of new instruments developed to guide manufacturers; prepare standards both national and International, in the field of instruments and assist services in assessing/evaluating foreign/indigenous instruments. They help in transferring technical know-how generated at the establishment to firms, both in Public and Private Sectors for establishing industrial base for the manufacture of modern and sophisticated instrumentation in the country.They also manufacture instruments on pilot plant scale to meet immediate requirements of the users till the transfer of technology is established in the country.They carry out basic and applied research work in the field of thin film optics technology, holography etc. as applied to instrumentation.

The Optics Technology group was basically created in IRDE to support the design activities so that the 'optics' requirements in connection with R&D work could be met from within the establishment. The group started with the manufacture of conventional lenses and prisms. However, over the years it has established the techniques for making precision optics to λ /20 and better surface accuracy, strain free polishing of thin plates, production of optical flats by optical contact method and so on. It has by now successfully produced optics varying in size from 2 mm to 200 mm, f/1 spheric for which special methods have been evolved for centering and edging to the required accuracy.

Techniques have also been established to process material like KBr, NaC1, KRS-5, Germanium and laser materials like Ruby and Nd glass. The technique of processing Nd Glass has been passed on to the CG CRI, Calcutta who have developed the material at their instance so that they can market the laser rods in finished form. Technique for making cylinderical discs and rings out of Yittrium-aluminum garnet in small sizes to an accuracy of ± 0.005 mm in dia has been established and some components have been supplied to the Communication Group of Space Application Centre, Ahmedabad in connection with their development work on Micro Wave Radiometer for use on board the satellite Aryabhatta.

The Group has also evolved a technique for the manufacture of a Schmidt corrector plate for use in a 200 mm catadioptric system with a view to reducing the overall size and weight of the system and for an improved optical performance. Making of a deep Schmidt plate is one of the most complex technologies in optical processing and the results achieved so far are very encouraging. A new method has been devised to ascertain the profile of a Schimdt Corrector Plate designed and fabricated at IRDE for use in large aperture F/1 catadioptric system. The method involves the measurement of effective focal length of various zones of the corrector plate using an auxiliary lens in combination. The zonal sagitta have been calculated and the profile of the schmidt plate under test has been plotted and compared with the designed values to guide the fabrication of the schmidt plate. A few prisms (90^{o}) of 8 mm face size in spectrosil quartz have been fabricated to an angular accuracy of one second of an arc for use in Q-switching of lasers.Steel mirrors of about 50 mm diameter have successfully been polished for use in a device under development at IRDE for tank guns. The reflectivity of the surface was found to be better than 85%. Mirror in glass has also been fabricated by hand touching method for use in a IR Device.

Precision spherical balls have many uses in the optical field, such as testing of optical components, collimation, determination of refractive index, fabrication of deep curvature test plates and for microscopic work. Spherical balls in glass have been successfully fabricated to an accuracy of one micron in diameter. Balls varying in diameter from 3 mm to 8 mm have been made using special techniques, viz,"two pipe lapidary" method for smoothing and "cage-held" method for polishing.

An optical polygon having eleven faces tilted at different angles with respect to each other and base planes was successfully fabricated for a Thermal Imaging Device to an angular accuracy of 30 sec of an arc and surface accuracy of λ /10 at 10 micron wavelength. The technique applied for the fabrication was unconventional one in which the optical milling machine in combination with dividing head was utilized for the generation of different tilts and angles of the polygon.

A computer program has been developed for optimisation of an optical system using the method of Linearisation under constraints so that it is corrected with respect to all the aberration. The program also includes routines for the evaluation of an optical system by using techniques like frequency response characteristics, spot diagram and energy distribution in the image plane. The program is written using

Fortran IV Language is run on IBM 370 system.

Hyperbolic asperical lenses are normally used as high quality condensers. A hyperbolic lens with one side plane (diameter 52 mm, focal length 25 mm) was fabricated with the help of a milling machine. The cutting feed in steps was established by the pre-calculated data for the known hyperbolic surface in the X and Y planes.

The lens grinding-cum-prototype development section was started at the Small industries Service Institute, New Delhi in 1961. The facilities at this centre were gradually added and as the programme of the centre was not very ambitious, it found for itself a limited role in training of technicians for cottage and small scale industrial units. It seems that the activities of this centre have been found adequate and useful by the industries around Delhi particularly by the ophthalmic industry. (CMTI) Central Machine tool Institute,(Est 1962) Bangalore is another public sector which is devoted to designing and development of optical technology. They make optical centring projectors, optical read out, auto-Collimators, and projectscopes.

National Aeronautical laboratory was started in 1959 and the optics work commenced from 1963. The Optics Group of National Aeronautical Laboratory with a primary responsibility of catering to the needs of this laboratory has during the years 1963-1970, developed various wind tunnel optical systems like schlieren systems of fields 100 mm to 150 mm, wind tunnel test section windows colour schlieren set up and Interferometer like machzehnder Interferometer. During the year 1971-80, schlieren systems of field 200 mm disc was developed and also work was carried on Holographic and Laser Interferometry.During the year 1981 to date Schlieren system of 300 mm field was developed and also work is going on development of Fibre Optics. They have capability of fabricating schlieren windows and mirrors upto 300 mm dia and also other optical components like optical flats, lenses & prisms.

Instrumentation and services unit of Indian Institute of Science, Bangalore was started in 1964. The department is called Central Instruments and Services laboratory. In addition to other instruments they also work on optical instrumentation. The department has a well established optical workshop. They have designed and developed several instruments, for example the centring and edging machines, 8 inch optical components for Mach Zehnder Interferometer 4 inch optical components for Twyman green interferometer.They have undertaken testing of precision optical components for various organisations and polishing of crystals.

In the field of Holographics a facility has been designed and built for holography and holographic interferometry. Techniques have been developed for the measurement of very small displacements (less than a fraction of wavelength of light), testing of optical components and for finding newer applications in the area of holographic interferometry. Successful application have been developed for the detection of leaks in pressure and vacuum vessels, flow visualization in water, measurement of physical parameters of thin films like thickness, stress, etc.

In Speckle metrology , measurement of change of refractive index in phase media, displacement, strain, vibrations, leaks in vacuum and pressure vessels, whole field filtering for total picture of displacements and displacement derivatives has been done. In the area of Fibre Optic Sensors, sensors using laser speckle in a multimode fiber has been developed for the measurement of current and magnetic field. Change in refractive index of liquid mixtures, thickness of electro-deposited films, etc.Optical picture processing is being attempted through modification of the Fourier spectra of the input image that needs processing. Several opto-mechanical methods are developed for the fabrication of Fourier plane filters for image processing. Non-coherent optical processing is being developed to reduce the effect of coherent noise in the processed image.

Variety of semi-conductor materials, in thin film form, are being studied, with pulsed Nd:Glass laser, for technologically important and novel optical memory devices.The R and D activity in thin films started in the latter part of the 60's and it is now possible to design, fabricate and evaluate thin film optical devices for a variety of applications. Current research work is in the improvement of deposition techniques and development of characterization instrumentation to obtain durable and absorption free dielectric coatings.

The Optics Section of the Bhabha Atomic Research Centre was started in 1966 as a part of the Spectroscopy Division which is a larger user of analytical instruments such as spectrograph, monochromators and spectrometers. The Optics section was set up to develop these items.

In the sixties, the IIT Delhi started activity in optics field in collaboration with Imperial College London, under the Colombo Plan. Besides training students in this field they have an optical workshop and testing facilities. They have a strong optical design group. They are now concentrating on Fibre optics and fibre optics communication.

At Indian Institute of Astrophysics optical fabrication dates back to the year 1964 with hand working of optical components in one of the rooms attached to the solar tower Kodaikanal Mirrors upto the size 15 inches were being worked by hand till the first machine capable of handling mirrors upto 30 inches in diamter was fabricated at Kodaikanal workshops. This machine, since operational, has been used for the fabrication of first 20 inch sphere which is now the camera for the coude spectrograph on 40 inch telescope. Later two 25 inches paraboloid for NAL and some other 24 inch and 30 inch optics for the institute, were fabricated.

The year 1976 had brought major addition in the facility of the optical workshop at Bangalore which includes new workshop building and a fifty inch machine for grinding and polishing with some additional facilities for fabrication and testing at Bangalore. A machine capable of handling mirrors upto 100 inches was commissioned in the same building in the year 1979, where an in-situ testing in a 25 m high vertical tower is possible. The complete workshop is air conditioned for better controlled working of optical polishing and figuring.

The design of many optical instruments like spectrographs, cameras, achromat lenses, correctors etc. have been developed at this Insitute. Many of the new fabrication and testing techniques have been established.

Besides these facilities in classical optics the Institute has an active group working on development of photoelectric detector systems for astronomical work. The projects cover applications of photomultiplier, solid state detectors and detector arrays, image intensifiers and scanning tubes. Computer interfaces for handling on-line data from these devices are also under development in this unit.24

Bharat Ophthalmic Glass Ltd, have also specialised in optical technology in recent years. They have succeeded in Design and Fabrication of Instruments, like Fizeau Interferometers with 8 inch master flat. Many types of vacuum evaporation and sputtering plants for optical thin films like laser mirrors, anti-reflection coatings, beam splitter coatings, dichroic coatings, etc.have been developed.

In optical fabrication they have been able to develop components, and techniques for rear view mirrors for gnat aircraft prisms for direct vision spectroscopes,Quartz optical components for space research Laser mirrors and Brewster windows Glass reflectors for 35mm movie projectors.

The ISRO Satellite Centre has also contributed to optical technology on a large scale since 1972. Large Space Telescopes are used as the main collecting optics of high resolution imaging systems like VHRR, MSS,etc. The technology for the fabrication of the several types of Telescopes has been developed. Infra-red optics is used in Horizon Sensors, VHRR, radiometers etc. Capability exists at ISAC for making infrared optical components upto a maximum size of 6 inches in diameter in various infrared transmitting materials. Some of the IR components have already been qualified in RS-D1 and RS-D2 satellites.

Retro reflectors are used for Laser Tracking of Satellites. Capability exists for making optical components like Retro-reflectors, alignment cubes, triangular prisms, at optics fabrication facility ISAC, These have been supplied to penta prisms, optical flats etc, at ISAC,VSSC SAC and STARS PROJECT Capability exists for making metal mirrors of various shapes in various metals, upto a diameter of 6 inches. A number of special optical components are needed in sensors like Encoder discs, rectangular glass blocks for sun sensors, Reticles, masks, etc. These are manufactured at ISRO Multi-element lenses are used in camera systems used in Satellites for Remote Sensing Payloads like TV Camera, LISS etc. Presently IRS-Camera lenses are being imported, but they can be produced in India. RS-D1/ D2 camera lenses were assembled at ISAC. All the fabrication and assembly techniques have been established. Multi-element catadioptric optical system used for wide angle applications are manufactured at ISAC's optics fabrication facility. They can design,and fabricate quality -multi-element catadioptric system for use in sensors and imaging systems using CCD array as detector. IRS Star Sensor optics was designed and fabricated here.

The Central Electronics Ltd (Est 1974)a government of India undertaking under the ministry of Science & Technology is located in Shaidabad U.P. They have complete range of optical, grinding, polishing facility with testing facilities namely interferometers, spherometers, Auto-Collimators in the

Workshop. They claim to make mono chromator IR spectro-photometers, N_2Lasers, Dye laser,CO_2Lasers Holographic 2 Replica grating and grating spectrographs.

A review of these reports clearly indicate that significant development in advance optical technology made a beginning in early sixtees with the development over the years The present state of the art is of an international standard and can meet the country's requirement to a great extent.

References

1. ANSARI,S.M.R.

   Introduction to modern western astronomy in India during 18-19 centuries.

   IHMMR, 1985.

2. KOCHHAR,R.K.

   Growth of modern astronomical instrumentation in India.

   IIA, Bull.Astr.Soc. India 16, p.12.(1988)

3. GODE,P.K.

   Some notes on the invention of spectacles and the history of spectacles in India between A.D. 1500 & 1800. Studies in Indian Cultural history, vol.III, 102-12,1969,Poona.

4. ANSARI,S.M.R.

   Archives internationales D'Histoire Des Sciences, vol.27, No. 101, December 1977. p. 240.

5.7,PHILLIMORE,R.H.

13 Historical records of survey of India

   vol.I-4 18th Century.Dehra Dun, 1945

6. RAO, N.K. VAGISWARI,A. & CHRISTINA LOUIS

   Father J. Richaud & Early telescope observations in India.

   Bull.Astr.Soc. India, 12, p.81-85, 1984.

8, ANSARI,S.M.R.
12,
   Astronomy in India during 18-19, centuries

   IHMMR, 1985.

9 . KHAN GHORI,S.A.

   Development of Zij literature in India.

   Indian Journal of History of Science vol.20 P.39-40

   1985,

10. SHARMA,V.N.
11,
Astronomical efforts of Sawai Jai Singh - A review, History of oriental astronomy, Proceedings of an International Astronomical Union, Colloquium No.91, New Delhi, India 13-16, November 1986.
CUP 235.

14. BLACK,E.D.
Memoir of the Indian Surveys 1875-1890.
London, HMSO, 1891.

14. LOUIS,G.O.
Survey of India, General report. 1938
Calcutta, Survey of India

14. THUILLIER,H.R.
25,
General report on the operations of the survey of India Department.
Calcutta, 1889.

14. NATIONAL INSTRUMENTS LIMITED
27,
28, 150 years of NIL An aide - Memoire 1982.

14. Northern flash Special annual 1987
220 year of survey of India 1767-1987

15. MARKHAM,R.
A memoir of Indian Surveys, London, 1878, p. 328

16 ANSARI,S.M.R.
On the early development of Western Astronomy in India and the role of the Royal Greenwich Observatory, Archives Internationales D'Histoire des Sciences, 27, p..243 1977.

17. SANWAL,N.B.
Bull Astr. Soc. India 11, 349, 1983

18. TOMKINS,H.G.

Obituary-The Observatory - 57, p. 284.1934

19. TOMKINS,H.G.

Note on photography and the physical condition of the Moon, MNRAS 88, 28 1927.

20. HARRISON,E.P.

Paper on the testing of parabolic mirrors.

The journal of Astronomical Society of India 1 (6), 11, 42 1910.

21. GURUMURTHY,K.

29,

Presidency college magazine, vol.12 112 1937

22. SUBRAMANIYAN,P.S.

Physics exhibition at Presidency College, Madras Centenary celebration record 1940, p..67-9.

23. BHATTACHARYYA,J.C. Optical telescopes in India

Ind. J. Pure App. Phys. 27, 311. 1989.

24. BHATTACHARYYA,J.C.

Optics activity in the Indian Institute of Astrophysics, Bangalore J. Optics 13, 60 1984.

26. LEWIS,C.G.

Survey of India general report

Calcutta, Survey of India 1938, p..70.

6. Conclusions

Prior to World war II country had been largely dependent on the supply of optical glass from other countries like UK & Germany. With exemplary efforts of Atma Ram and other senior colleagues we have already come a long way. There is enough raw material available and CGCRI is able to produce variety of optical glasses of international standards. First successful production of optical glass on a pilot scale was at CGCRI in the year 1958. Technology & trained man power both are now available, only the confidence level has to be increased in the use for the indigenously produced optical glass. It is also important that this knowledge and experience of optical glass making should be spread to other institutes and organisations.

Big establishments like BOGL have great scope of utilising the available technology but perhaps there is a need of organisational reforms and better utilisation of available knowhow.

A greater demand for a variety of optical glass in our country and in the neighbouring countries is visualised. Boost in the production and quality assurance is imperative. Also there is scope for few more special quality glasses and glass ceramics though their demand is presently low.

Most of the early efforts in optical technology was directed towards repair and manufacture of survey instruments. East India Company was keen to have accurate maps and devoted much of its time to survey work. This necessitated the import of many optical instruments, which needed maintenance and repairs and hence we find the establishment of Mathematical Instrument Office to under take this work. M.I.O.was not meant to be a production unit in the beginning but just a repair workshop. Later it slowly undertook manufacturing of optical components and instruments as the need grew.

We find that in the private sector lawrence and Mayo started their concern in 1877 which was about 100 year after MIO was established. Some stray indegeneous attempts like making of spectacles from vallam crystals was found in 18th century. But it is not clear what instruments they used. It seems like, they had deviced their own grinding and polishing machines made by the local artisans.

The role of ameteur astronomers like Tomkins can be considered as one of the earliest attempts in fabrication technology. It is solely his interest with out much help from others, that he was able to design and fabricate a machine for grinding and polishing of optical mirrors upto 24" size.

Andhra Scientific Company in 1930 seems to be the first indegeneous effort to produce optical instruments in a big way. The other firm, S.K. Dhar and Company in Calcutta also contributed significantly in developing the technology. They were master craftsman of their time.

We do not find wide spread and concerted efforts throughout the country though technology existed. It remained a local effort like we hear of prof. Parameswaran at Presidency College, Madras and Tomkins at Calcutta.

Post war period in early sixtees saw the mushrooming of many small and medium sized industries both in private and public sector. Besides producing optical components, they also manufacture optical instruments.

The utilization of the technology is more in the educational institutions and defence departments. In recent years demand has increased for optical components and instruments and both private and government organisations are putting in their efforts to reduce imports and improve the quality of their products to achieve International standards. There is larger scope in the field of optical technology as new areas are opening.

Appendix 1

QUESTIONNAIRE

1. Name of the Organisation :

2. Present address :

3. Year of establishment and activities :

4. Other centres of your establishments, if any :

5. Name of the collaborators, if any : INDIAN

FOREIGN

6. Past and present major activities and achievements (A brief account with relevant dates to be given. Please also give the names of persons actively involved. Attach a separate sheet if space provided is not sufficient). :

(i) Optical Technology :

(ii) Optical Glass Work :

(iii) Optical fabrication :

7. Do you have an R&D Department if yes, please give a brief description of the facilities and areas of work : YES NO

Any printed information available relevant to the above questionnaire is welcome.

APPENDIX 2

SOME OF THE LEADING ORGANISATIONS IN THE FIELD OF OPTICAL TECHNOLOGY

S.No	Year of Establishment	Name of the organisation	Activities
1.	1767	Geodetic & Research Branch Survey of India. 17-EC Road Post Box No.77 Dehra Dun-248001	Surveying and mapping in the Country, R&D, repair, calibration, standardisation, training in the field of optical and electro-optical survey instrumentation. Developed the following instruments : Optical Comparators, Argon lamp Transverse Target Electric signal Automatic secondary level Electro-optical distance measuring instruments.
2.	1830	National Instruments ltd., 1/1 Raja Subodh chandra Mallick Road Jadavpur. Calcutta-700032	Manufacture of opto-mechanical, opto-electrical, opto-electronics instruments During the period of World War I & II binoculars, surveying instruments & transit theodolities were produced. IR sighting devices, low level illumination passive systems, laser range finders etc., are produced for defence Organisations.

			Glass blowing for industrial thermometers are in regular production line.
3.	1877	Lawrence & Mayo (India) Private Limited 274 Dr. D.N.Road Bombay-400001. Branches in New Delhi Madras, Bangalore, Hyderabad & Calcutta.	Manufacture of ophthalmic optics Magnifiers for use in Diamond industry, Goggles war period single vision and bi-focals, did lens grinding first time in India.
4.	1908	Nizamiah & Japal Rangapur Obser-vatories Department of Astronomy Osmania Univer-sity Hyderabad-500007.	Astronomical research and teaching.Fabrication of auxiliary instruments for use with 1.2m telescope of the Observatory
5.	1926	Bharat Electro-nics Limited Ravindranath Tagore Road, P.O.Box No.26 Machilipatam-521001	Production of optical and opto-electronic equipment The Andhra Scientific Co.,estd. in 1926 was producing physical laboratory instruments and balances and the company merged with BEL in 1983. Since 1945,manufacturing instruments.Undertakes Optical designing and fabrication and Produces various types of clinical and biological measuring telescopes, spectrometers, interferometers etc.

			They manufacture instruments like Fire control instruments large apertures Spectrometers Microscopes Theodolities interferometers large aperture parabolic reflectors prisms Night vision equipment At present the Unit is engaged in night vision equipment, sighting equipment, Indirect daylight sight equipment passive night observation devices with laser range finders. In 1987-88 introduced latest high-speed optical processing technologies. Also introduced new optical production of plane parallel plates and precision prism utilising planetary lapping process and annular continuos polishing methods.
6.	1941	Indian Emporium Rampur Road Roorkee, 247667	Manufactures optical surveying, drawing and mathematical instruments.
7.	1943	Indian ordnance Factories, and Ordnance Factory Raipur Dehra Dun. U.P.-248008	Production of sighting and ranging instruments, infrared coatings and night vision (passive) devices, Reflection, anti-reflection coatings on optical components, beam spiliters, production of lenses upto 200 mm dia and upto 1/4 λ accuracy, photo-printing and photo etching work of high quality and wide

			variety of cemented optics and roop prisms of the highest quality.
8.	1943	Jyoti Limited Baroda P.O. Chemical Industries Baroda-390003 Gujarat.	Specialises in laser optics. Offers laser alignment system holography, ND yag pulsed Laser
9.	1945	Hindustan Ophthalmic lens Mfrs Baroda Opp Kothi Bus Vasodara-390001	Rough blanks imported from Foreign countries are ground and polished
10.	1949	Jaisons & Sons. 7th Cross Road Ambala Cantt 133001	Manufactures opto-mechanical, electrical instruments, and industrial projectors and testing instruments
11.	1950	National Physical Laboratories hill side Road New Delhi-110012	The laboratory has a strong group working on the developments of various optical thin film techniques.
12.	1952	Budh Singh & Sons C 3 industrial Estate Roorkee-247667	Manufactures optico-mechanical equipment for civil engineering department and Defence use makes development lenses for surveying and scientific equipment makes telescopes, mirror extensometer, optical roller extensometer for testing of material.
13.	1953	Optical Instrumentation 21, Beadon Pura Karl Bagh New Delhi-110005	Makes optical components for all types of instruments Makes focimeter-an import substitute

			Manufactures sopt Reniscope and telescopes.
14.	1954	Optical Engineering Laboratories 6/442-Kojjilipet Muslipatam	Manufactures Crystal optics and associated instruments The Laboratory is mainly concerned with production if crystal optics technology
15.	1954	Uttar Pradesh State observatory Manora Peak Nainital-263129	Has capabilities to make Solar spectrographs and Solar coelostat mirrors
16.	1956	Telecommunication Research Centre Kursland Lal Bhavan Janpath-110001	Undertakes design and development of telecommunication systems for India posts & Telegraphs Department. In this connection they have developed optical fibre communication system. TRC is coordinating with some of the R&D organisations and associating with leading Foreign manufacturers to assess the trends in this direction.
17.	1958	M/s Electrofones Science House Jagadhari Road P.O.Box 15 Ambala Cant-133001	Manufacturing Scientific instruments like spectrometers,travelling microscopes,research optical benches,bi-prism assemblies and polarimeters for schools, colleges

18.	1959.	Central Sceintific Instruments Organisation Sector 30 Chandigarh 160020	Engaged in research design and development of instruments pertaining to various disciplines of Science & technology with Applied Optics as one of the major activities
19.	1959	National Aeronautical Lab. Post Bag 1779 Bangalore-560017	R&D aeronautics Fabricating Schlieren windows and mirrors upto 300 mm.dia and also other optical components like optical flats, lenses and prisms.
20.	1960	Instruments Research & Development P O.Raipur Dehra Dun 248008	To design and develop various types of optical,electro-optical, optronic,servo,fibre optic and holography based instrumentation To carry out investigations on major defects existing in instruments and suggest solutions. To carry out basic and applied research work in the field of thin films optics technology, chemical technology, holography etc., as applied to instrumentation.
21.	1961	Small Industries service Institute New Delhi	Has a grinding cum prototype development section Technicians training section for cottage industry
22.	1962	Central Machine Tool Institute Tumkur Road Bangalore-560022	Research and development in machine tools Design and development optical instruments such as optical centring projector, optical readout, Auto-collimator project-scope.

23.	1963	Towa Optics (India) Private Ltd 4C Ansari Road New Delhi-110002	Manufacturing micro-scopes, eye pieces and objectives and other optical and scientific lenses
24.	1964	Instrumentation & Service Unit Indian institute of Science Bangalore-560012	R & D of instrumentation Research activities Servicing and maintenance of all kinds of instruments including optical instruments Research and developments of instru-mentation, research services, serving and maintenance of instruments
25.	1964	Indian Institute of Astrophysics Koramangala Bangalore-560034	It has the biggest optical workshop of its kind in the country. Capable of producing large telescopes of 100 inches diameter. It can do coating of mirrors upto the same size.
26.	1966	Bhabha Atomic Research Centre Trombay Bombay	Optics section designs and develops spectro-graphs monochromators and spectro-meters.
27.	1967	Harvin Optical & Glass Industries 7C-34 Industrial Estate Sanatnagar Hyderabad	Manufacture of optical lenses and prisms
28.	1967	opticolite industries 8-17/C Lane 9 Anand Parvat Industrial New Delhi-110005	Manufacturing of laboratory optics mainly for export precision optical components made from optical glass quartz
29.	1967	Vacuum instru-ments Company 81,Regharpura new Delhi-110005	Manufacture of scientific apparatus for research and Industry

30.	1968	Bharat Ophthalmic Glass Limited Lenin Sarani Durgapur-713210	Production of ophthalmic lenses optical glasses, large size discs,prism blanks of wide varieties,filter glasses etc.
31.	1960 s	Optics group IIT Delhi	Has a optical workshop with designing and testing facilities Concentrates on Fibre optics and Fibre optics Communication.
32.	1970.	Spectro Systems (P) Limited MSR Industrial Estate Gokula ext.Bangalore 560054	Manufacture of optical components
33.	1972	ISRO Satellite Centre Vimanapura Bangalore-17	Satellite and spacecraft systems including Electro-optical sensors.
34.	1972	Spectro Lase F 64 Bhapal Singh Market New Delhi 110001	Manufacture of lasers, holographic equipment vacuum coatings, thermometer production machines and electronic instruments.
35.	1973	Tej optical Works Roshan Road hoshiarpur	Manufactures wide angle optical lens systems.
36.	1974	Central Electronic Limited 4 Industrial area Sahidabad U.P.-201010	Monochromator,IR spectrophotometer,N laser, Dye laser Co_2 laser,holographic and replica gratings, optical components, grating spectrograph, hot box detector etc.,
37.	1977	Industrial Optics 20/8 NSC Bose Road Calcutta-700040	Fabrication of optical components, mechanical components,anodising of metal parts.

38.	1977	Optiregion 13/28 Sakhti Nagar Delhi-110007	Supply's optical cpmponents to space centres, IRDE, R&D Labs like IITs, Defence Centers, Universities & Engg. Colleges. Capable of developing and fabricating any precision optical component and system.
39.	1978	Bishwanath Photo Engraving Works Ladpur P.O. Raipur Dehra Dun-248008	Manufacturing graticules, lenses. prisms, spirit bubbles and optical instruments.
40.	1978	Pujab Electro-optics systems Limited F3-10 Industries Focal point SAS Nagar Punjab.	Manufacturing sophisticated optical instruments and components.
41.	1979	Lensel Optics (P) Limited 66/2 DII MIDC area Chinchwad Pune-411019	pioneeing unit in the field of Plastic optics. Products consist of plastic lenses used in the diverse applications such as condensers; illuminated magnifiers, TV screen magnifiers, visual aid etc.,
42.	1981	Hindustan Aeronautics Limited Korwa Division Barabank Road Post office HAL Lucknow-208016	Navigation and attack systems for advanced aircraft for IAF
43.	1983	Center for laser Technology IIT Kanpur-208016	Fabrication of lasers, instruments, coherent optics, fiber optics, Laser spectroscopy, materials processing, Lasers in teaching.

44.	1980's	Physical Research Lab Ahmedabad	Various optical coatings have been developed which are used in several research programmes and a project of fabricating a micro-processor controlled spectrophotometer-cum calorimeter.

38.	1977	Optiregion 13/28 Sakhti Nagar Delhi-110007	Supply's optical cpmponents to space centres, IRDE, R&D Labs like IITs, Defence Centers, Universities & Engg. Colleges. Capable of developing and fabricating any precision optical component and system.
39.	1978	Bishwanath Photo Engraving Works Ladpur P.O. Raipur Dehra Dun-248008	Manufacturing graticules, lenses. prisms, spirit bubbles and optical instruments.
40.	1978	Pujab Electro-optics systems Limited F3-10 Industries Focal point SAS Nagar Punjab.	Manufacturing sophisticated optical instruments and components.
41.	1979	Lensel Optics (P) Limited 66/2 DII MIDC area Chinchwad Pune-411019	pioneeing unit in the field of Plastic optics. Products consist of plastic lenses used in the diverse applications such as condensers; illuminated magnifiers, TV screen magnifiers, visual aid etc.,
42.	1981	Hindustan Aeronautics Limited Korwa Division Barabank Road Post office HAL Lucknow-208016	Navigation and attack systems for advanced aircraft for IAF
43.	1983	Center for laser Technology IIT Kanpur-208016	Fabrication of lasers, instruments, coherent optics, fiber optics, Laser spectroscopy, materials processing, Lasers in teaching.

44.	1980's	Physical Research Lab Ahmedabad	Various optical coatings have been developed which are used in several research programmes and a project of fabricating a micro-processor controlled spectrophotometer-cum calorimeter.