SHANTI SWARUP BHATNAGAR*

1894-1955

Foundation Fellow 1935

IN PROFESSOR SIR SHANTI SWARUP BHATNAGAR we had a man of extraordinary parts. Not only was he eminent as a scientist, but he held a record as an administrator and organizer. He exhibited high poetic talent particularly in Urdu. The testimony of one of his teachers that he was good in all subjects of study and did well in anything that he undertook as a student, is applicable fully to his life's work in its various aspects. He lived in a period of active change in the life of the Indian people and played a remarkable part in the development and organization of scientific research in the country. By birth and upbringing he seems to have been the right person for the task.

Childhood

He was born on 21 February 1894 at Bhera, in the district of Shahpur in Punjab (India). He was the second of three children, the eldest being a sister and the youngest a brother. His father Parmeshwari Sahai Bhatnagar was a distinguished graduate of the Punjab University and gained distinction in English and history. His mother Shrimati Parbati Bhatnagar was the eldest daughter of Mr Pearey Lal who was one of the first to qualify as an engineer from the famous Roorkee College. His paternal grandfather Rai Bahadur Munshi Manohar Lal Bhatnagar and his brothers held high executive and judicial posts. His grandfather was particularly noted for his piety and honesty. His father was a puritan and joined the Brahmosamaj. He persistently refused to take up judicial or executive service which was the family tradition and became the headmaster of a high school in Bhera. Consequently though the main family was in affluent circumstances he lost his share of the family property and was disinherited. This did not diminish in any way his zeal as a social reformer but when he died he left his wife and young children in dire poverty. Shanti Swarup was then only eight months old and he received a great deal of attention from his maternal grandfather, who had become a distinguished engineer and was employed in railway construction work. Under his influence the child developed a taste for engineering and science. He became interested at a very early age in his grandfather's instruments, Euclid and algebra, and in making mechanical toys.

His mother's family produced a number of poets, the most famous of them

* Reproduced from the *Biographical Memoirs of Fellows of the Royal Society*, Volume 8, 1962.

S. S. Bhatnagar

was Munshi Hargopal Tufta who got the title of Mirza from Mirza Ghalib, the greatest Urdu poet which India has produced. Tufta wrote largely in Persian and his poetical works constitute a definite volume. Shanti Swarup's taste and irresistible desire to dabble in Urdu poetry came as inheritance from his mother's side.

School Days

His earliest schooling was in a private 'maktab' which he joined in 1901. Later, up to the year 1907 he studied in A.V. High School Sikandrabad in U.P. where his maternal grandfather worked. In 1908 Rai Sahib Lala Raghunath Sahai, a classfellow and friend of his father, met the family in their home at Panipat. As a famous headmaster, his one hobby was to collect young school boys and examine them. He found young Bhatnagar specially good in literature and sciences and persuaded his mother to send him for schooling at Lahore in Dyal Singh High School. As he was the eldest son of the widowed mother, she at first hesitated but when she realized that education at Lahore would be of great help to her capable son and that there were chances of his getting a scholarship, she agreed. In Lahore he secured a high-school scholarship in open competition and used to earn his living by teaching younger boys privately. The headmaster who later on became his father-in-law was a great inspiration in that formative period, during which he also came in touch with two leading Brahmos, Pandit Shiv Nath Shastry and Babu Abinash Chandra Mazumdar and became highly interested in the Brahmo Samaj—a movement which was originally started by Raja Ram Mohan Roy and which was somewhat akin to the Unitarian Christian Movement.

In the school he was considered to be distinctly high up in literary attainment particularly in Urdu. He was so proficient in Urdu grammar and Urdu poetry that his teachers thought that his attendance in these classes was unnecessary; he was also a very inquisitive student of science. On the occasion of his election as Fellow of the Royal Society, one of his oldest teachers Moulvi Talib Ali Paband who was at that time over eighty years of age wrote as follows: 'Your election to the Royal Society is a matter of special pride to me as I believe I am your first teacher who taught you sciences. From the very beginning I told you and the Headmaster of the School that you were going to make a mark in life. I could not say that you would become a Fellow of the Royal Society, but I knew you would rise to great heights. My joy is further heightened by the realization that I not only taught you but also Lajwanti who is your wife and is well known as Lady Bhatnagar.'

Besides the headmaster of the school who was his friend and guide and whose puritanical view of life, scholarly interest and religious fervour had great influence on him, he was also taught by Rai Bahadur Lala Ram Kishore, a man of great intelligence and powerful expression of speech and writing, who later rose to be an eminent lawyer and also the Vice-Chancellor of the Delhi University. He learnt sciences from the Moulvi mentioned above and from Mr Mohd. Ashraf and Lala Bishen Narain Mathur who later went to America and returned as a leather expert. The experiments which interested him were largely in the electrical field, producing string telephones and electrical batteries. As early as 1911 young Bhatnagar published a letter in the *Leader* of Allahabad on a method of making substitute carbon electrodes for a battery by heating molasses and carbonaceous matter under pressure. This is rather significant since later in 1942 he developed in the D.S.I.R. laboratories a process for carbon electrodes in which indigenous Indian materials were employed to meet the shortage of imports during the war.

University and Higher Education

After passing the matriculation examination in the first division and securing a University scholarship Bhatnagar joined the Dyal Singh College, Lahore, in 1911. This college had been started a year before and had a staff of which any institution could be proud. The professor of English Literature was Professor P. E. Richards, a distinguished Oxford graduate and a great scholar. His talented wife, Mrs Norah Richards, made great contribution to the literary life of the college by her learning and keen interest in modern drama and Shakespearean plays. She inaugurated the Saraswati Stage Society in Lahore of which Bhatnagar became an active member. He was chosen for many important parts in plays which she staged and his reputation as an actor was distinctly good. As a result of the impetus she gave to playwriting in Urdu, Bhatnagar became an amature playwright and wrote in Urdu a one-act play called 'Karamati (Wonder-worker)'. This was translated into English and he was awarded the prize and medal of the Saraswati Stage Society for the best play of the year 1912. During this period he also wrote a paper on investigations on 'Fermentation of pomegranate juice' which was published in *Raushni*.

After passing the Intermediate Examinations of the Punjab University in 1913 in the first division, he joined the Forman Christian College for the B.Sc. degree. The principal of this College was Dr J. C. R. Ewing, the famous American missionary who later became Sir James Ewing and was for many years Vice-Chancellor of the Punjab University. Here he studied physics and chemistry and took up an Honours course in physics. This subject was taught by Professor J. M. Benade, M.A. (Princeton), who was excellent in experimental physics and in the workshop and had done research with Professors K. T. Compton and A. H. Compton. Bhatnagar did his first piece of research work with him for the M.Sc. degree on the subject of surface tension. Chemistry was taught by Professor P. Carter Speers who was called the father of technical education in the University. Among other teachers whom he remembered with affection were Dr Lucas and Dr Rice; Mrs Rice was a sister of Professors K. T. and A. H. Compton of the U.S.A. He took the

Bachelor's degree in 1916 and as by that time he had got married, he accepted a demonstrator's post in the physics and chemistry departments of the Forman Christian College and later the Senior Demonstrator's post in the Dyal Singh College. Subsequently he joined the M.Sc. course in chemistry in the Forman Christian College and took the degree in 1919, after having submitted in part fulfilment of the requirements a thesis on the subject 'Effect of adsorbed gases on the surface tension of water'.

As a university student Shanti Swarup made very good impresion on his teachers. Mr Welinker, Principal of Dyal Singh College who later became Director of Public Instruction wrote, 'Mr Shanti Swarup was one of the ablest students in that large class of about 100 students; indeed, I am of opinion that in all-round ability he was the ablest. He distinguished himself in every branch of the work of his class—literary, scientific, dramatic, social —and he gave the most complete satisfaction to the Professors by the excellence of his behaviour. He is a young man of more than usual ability and I feel sure that if he is given opportunities of developing his talent in some great European or American Centre of scientific research he will do some remarkable work in science and will thus be in a position to render high service to his country.'

Amongst other teachers whom he remembered with gratitude were Professor B. M. Jones, later Vice-Chancellor, Leeds University, Professor B. K. Singh and Professor R. R. Sahni. The last took special interest in him and was largely responsible for the award of a scholarship from the Dyal Singh College Trust for his studies abroad. He started for America via England in August 1919. When he reached England, he found that all tickets to America had been fully booked for American troops which were then being demobilized. He therefore wired to the Trustees of the Dyal Singh College and they agreed to his doing post-graduate research in London. As his subject of special study was surface tension and surface properties and as he had already read of the great work of Professor F. G. Donnan, F.R.S., of the University College, London, he presented himself to him with his papers. The Professor very kindly agreed to take him under his care for the D.Sc. degree of the London University. After two years of work in the Ramsay Laboratories he submitted a thesis entitled 'Solubilities of bi- and trivalent salts of higher fatty acids in oils and their effect on the surface tension of oils' and received the degree in 1921. During this period he had a fellowship of the value of £250 a year from the D.S.I.R., Great Britain.

From amongst his colleagues at the University College could be mentioned the following:

(i) W. E. Garner, later Professor of Physical Chemistry in Bristol University; (ii) J. C. Ghosh, later Sir J. C. Ghosh, Director General of Industry and Supply and finally Member, Planning Commission, Government of India, New Delhi; (iii) J. N. Mukherjee, later Director Indian Agricultural Research Institute and Member Union Public Service Commission, New Delhi; (iv) M. N. Saha, later Palit Professor of Physics, Calcutta University;

(v) J. Samejima, later President of the Chemical Society, Tokyo; (vi) Papa Constantinou, later Professor, University of Athens; (vii) R. E. Slade, later of the I.C.I.

During summer vacations he was a research student in the Kaiser-Wilhelm Institute, Dahlem, Berlin, and also in the Sorbonne, Paris, and came into intimate touch with Professors Haber, Freundlich, Bodenstein, Nernst, Einstein, Planck, Urbain, and Perrin. He travelled widely in Europe and visited a number of institutions famous for research work in physical chemistry.

As University Professor

On his return to India in August 1921 he was appointed Professor of Chemistry in the newly started Banaras Hindu University and he worked there for three years creating an active school of physico-chemical research. He then migrated to Lahore on his appointment as University Professor of Physical Chemistry and Director of University Chemical Laboratories; he was later elected Dean of University Instruction of the Punjab University. During the period of active teaching and research in the two Universities he had a large number of able students and collaborators. Amongst them the following have specially distinguished themselves in higher teaching and research: Professor Mata Prasad, Principal, Royal Institute of Science, Bombay, and later Director, Central Salt Research Institute and Vice-Chancellor Vikram University; Professor S. S. Joshi, Professor of Chemistry and Principal, College of Science, Banaras University; Dr D. L. Shrivastava, Deputy Director, Central Drug Research Institute, Lucknow; Dr K. N. Mathur, Deputy Director, National Physical Laboratory, Delhi, and later Director, Scientific Instruments Organization; Professor B. D. Jain, Professor of Inorganic Chemistry, Delhi University; Dr Balwant Singh, Professor, Government College, Ludhiana; Professor T. N. Seth, Professor of Bio-chemistry, Medical College, Patna; and Professor Bashir Ahmad, Director, University Institute of Chemistry, Lahore, and later Vice-Chancellor. He took great and intimate interest in his pupils and many were the unknown acts of kindness and generosity.

The 16 years (1924-40) as Professor in the Punjab University was the most active period of his life for original scientific work. Bhatnagar had a reputation as a very inspiring teacher and it was as a teacher that he himself was most happy. Not only was he a great experimenter but he was also a well-read and gifted writer. The major fields of study were colloid chemistry and magneto-chemistry. However, he did considerable work in applied and industrial chemistry in which he had a natural interest from his early student days. One of the striking and characteristic achievements of this period was the work he did for Messrs Steel Brothers & Co,. London. Representatives of this firm were faced with what they called their mud problem. In the process of drilling for oil, the Attock Oil Company at Rawalpindi were using a drilling mud which when it came into contact with saline water set into a solid mass which hardened further and rendered all drilling impossible. The problem was elegantly solved by the addition of an Indian gum which had the remarkable property of lowering the viscosity of the mud suspension and of increasing at the same time its stability against the flocculating action of electrolytes. The firm was so pleased with the result that they offered a sum of one lakh and fifty thousand rupees to Bhatnagar for his research work on any subject of petroleum interest. But he desired that the gift should be made through the University and eventually the Company conveyed the financial grant to the Vice-Chancellor. This provided for salaries of research assistants and also for chemicals and apparatus. The unit was inaugurated as a department of petroleum research under his guidance. Later this amount was increased and the period extended from five to ten years. About six research scholars were engaged in this scheme and the scholarships were named after five eminent men of Punjab and Professor Donnan of London. His great interest in the workers was shown not only by liberal provision for their emoluments but also by his care for their provident fund and for their medical attention. As a result of this scheme important investigations were carried out on the subjects of deodorization of waxes, increasing the flame height of kerosene, lubrication, prevention of corrosion and utilization of waste products in the vegetable oil and the mineral oil industries. The results were of great industrial value. Bhatnagar also offered fifty per cent of all income out of patents to the University to be mainly devoted to scientific research work. These were acts of great generosity and were important for the promotion of scientific and industrial research; not only the Vice-Chancellor and the Syndicate of the University but also his friends and national leaders congratulated and honoured him. This personal example may provide the key to his later success in securing benevolence from public and private sources for scientific research.

He persistently refused to accept financial reward for himself personally. This was due to the conviction grown on him that scientific work loses its altruistic and truly cultural character if the worker becomes money minded and begins to secure financial benefits for himself. Further the public begins to doubt the sincerity of a worker if he works hard in order to make himself rich. Students derive inspiration only from a selfless worker. That his spirit of self-sacrifice was much appreciated by all in the country was evident from the large number of letters from his friends and well wishers and the numerous occasions on which this was mentioned during convocation addresses, annual meetings of the Indian Chamber of Commerce and the sessions of the Indian Science Congress.

As typical of the sentiments expressed at that time is given below an extract from the Convocation Address of the Right Honourable Sir Tej Bahadur Sapru to the Punjab University in 1936: 'When, therefore, I read the other day in the newspapers that Messrs Steel Brothers & Co, London, had in recognition of the great work done by Dr Bhatnagar, made a very generous gift of money to him and that he had with a singular sense of patriotism and self-denial transmitted a considerable part of that gift to the Chemical Department of your University, so as to create an Industrial Research Department, in which some research scholars could develop new processes for the industrial utilization of Indian raw materials, I felt that your University was lucky in possessing a Professor who was alive to his duty to the country and was not afraid of being accused of doing something practical for the good of the country'.

As coming from a distinguished scientist, the following is an extract from the letter of Professor M. N. Saha, F.R.S., who was then Professor of Physics in the Allahabad University. 'Please accept my heartiest congratulations on your noble gift to the Punjab University. You have thereby raised the status of the university teachers in the estimation of the public, not to speak of the benefit conferred on your Alma Mater. India does not lack in men earning millions, but if a few of those millionaires were guided by the fine example set by a comparatively poor teacher like yourself, I think her scientific and moral progress would have been rapid. Nobody but a true researcher can feel how much our energies in this country are being wasted for lack of funds.

'Once more, in cordial admiration of your noble deed.'

As Director of Scientific and Industrial Research

The year 1940 saw a big change in Bhatnagar's life and work. When the Second World War broke out, the Government of India established the Board of Scientific and Industrial Research and commandeered the services of Dr Bhatnagar as director. Though earlier he had declined tempting offers of posts in industrial research, he took this up as national service. The laboratories of the Board were first located in the Government Test House at Calcutta. When threats of the Japanese invasion became more intense these were shifted to the Delhi University and the name was changed into the Council of Scientific and Industrial Research. In spite of heavy administrative duties he was able to devote sufficient time to research work and during this period several patents of great importance were developed by him and his staff. Among them may be mentioned the following items of significance for the war effort: anti-gas cloth and varnish, air-foam solution, vegetable oil blends as lubricants and fuels, unburstable containers, glass substitutes, dehydrated castor oil and plastics from Indian wastes.

For several years earlier and particularly during the war considerable public interest was shown for the establishment of national laboratories. Concrete suggestions were made by special committees of Government to give effect to these proposals. But it was Bhatnagar who put heart and soul into the establishment of the chain of national laboratories. Before his death twelve of these laboratories were fully functioning, and as a result of the impetus given to the programme by him more than an equal number of newer ones have come into existence during the past fourteen years. These laboratories are not small institutions. They can vie with the best of their compeers in any part of the world. In the March 1952 issue of *Physics To-day* published from Washington, Dr L. S. Curtiss wrote as follows: 'Perhaps the most notable example of the efforts to improve the position of physics in India which came to my attention is the New National Physical Laboratory at Delhi. It is easy to predict that this laboratory will, when in full operation, contribute handsomely to the progress of physics not only for the benefit of India but the rest of the world as well. Even in its present incomplete state the building in size and attention to detail represents a structure that would form a prized acquisition by any Government. In addition it seems to stand as a symbol of the kind of progress to be expected in a country which has already made valuable contribution to the advancement of physics.' Earlier in January 1950 at the opening of this National Physical Laboratory Sir Robert Robinson, President of the Royal Society, spoke about Bhatnagar in the following words: 'We cannot forbear from adding a personal message ot congratulations to Sir Shanti Bhatnagar who is so well known to us and whose practical initiative and capacity for action has made possible the realization of his dreams,' and elsewhere he said, 'It was fortunate indeed that at this critical time in history, when every iron is hot upon the anvil, India found in Shanti Bhatnagar an eminent scientists of clear vision, sound judgement in affairs and boundless energy in action. His high office has enabled him to realize wisely ambitious plans and today we see the concrete results, a dream come true and one I suspect that lies especilly close to his heart.'

As director of Scientific and Industrial Research Dr Bhatnagar had to serve under several members of the Viceroy's executive council such as Sir A. Ramaswamy Mudaliar, Sir Azizul Haque, Sir Ardeshir Dalal and later, when the Congress took over the government, under Shri C. Rajagopalachari and ultimately under the Prime Minister Shri Jawaharlal Nehru. He was able to carry through his work with characteristic smoothness and speed with chiefs of such divergent character and tastes. This was largely due to his great tact, resourcefulness and adaptability and more than these his devotion to work. Later his tasks were comparatively lightened because the Council of Scientific and Industrial Research was placed under the Prime Minister himself who was equally enthusiastic in the development of science and of national laboratories.

Bhatnagar's interest in science and its practical utilization was very wide and he did a great deal of pioneering work especially on the organizational side. Among these may be mentioned the establishment of the National Research Development Corporation of India, which fills the gap between research and development and contributes to India's economic and industrial progress. He was responsible for the initiation of the Industrial Research Association Movement in India. Before his death three research associations had already come into being and many others came soon after. He laid emphasis on conservation and processing of minerals. This resulted in the installation of a heavy media separation plant for beneficiation of manganese ore which was the first of many similar developments. The favourable position of India for undertaking the production of newer metals was emphasized by him and the methods of production were subjects of investigation in national laboratories. The establishment of a factory known as India Rare Earths Limited to process monazite sand, and intensification of search for atomic minerals, for sulphur-bearing ores and for petroleum deposits are large items that could be mentioned under this category. He constituted the one-man commission in 1951 to negotiate with oil companies for starting refineries in India and this ultimately resulted in the establishment of many oil refineries in different parts of the country. The cause of science and education was always close to his heart and he induced many persons and organizations to donate liberally for this purpose. The institution of Burmah Shell and Assam Oil Company scholarships at a cost of rupees 2 lakhs per annum and a donation of £100, 000 to Nagpur and Saugar Universities by C. P. Manganese Ore Company are examples of his success in this direction.

During the closing years of his life, he cheerfully carried the burden of multiplicity of posts. In 1947 and 1948 he worked as Secretary to the Ministry of Education and Educational Adviser to Government of India. He was chosen to become the first Secretary to the Ministry of Natural Resources and Scientific Research which was set up in 1951 and this was linked up with the post of Director of Scientific and Industrial Research; he was also Secretary of the Atomic Energy Commission and later became the Chairman of University Grants Commission. In addition he had to work as member or president on committees and official advisory bodies of which the number is too large to be listed. Though he took up cheerfully so many responsible assignments because he could not refuse any work of importance, they seem to have rapidly undermined his health.

Honours

With his great enthusiasm and energy and interest in work of national importance, he came into contact with many organizations and leading men. Appreciation and recognition came in freely and in abundance. In 1936, Government conferred on him the O.B.E. based on his excellent work in pure and applied chemistry. He was knighted in 1941 in recognition of his work for the war effort. In 1943 the Society of Chemical Industry, London, elected him an Honorary Member and later Vice-President. On the election to the Honorary Membership the testimony states: 'That on Monday, January fourth in the year 1943 at the Royal Institution, London, the rare distinction of HONORARY MEMBERSHIP OF THE SOCIETY OF CHEMICAL INDUSTRY was by the order of the Council and in the presence of a large gathering of Members CONFERRED BY THE PRESIDENT DR WILLIAM CULLEN ON SIR SHANTI SWARUP BHATNAGAR, a Doctor of Science of the University of London and Director of the Department of Scientific and Industrial Research of India in commemoration of his life-long activities as a Research worker in the realm of pure and applied chemistry which branches of science he has enriched by his pioneer work. The COUNCIL in deciding to bestow this honour selected with great care one whom they considered worthy, for in addition to his manifold contributions to our knowledge, he has through his selfless devotion to his scientific and academic duties done everything possible to maintain the status and dignity of the Chemical Profession'.

The same year (1943) he was elected Fellow of the Royal Society, London. He received honorary degrees from a large number of Universities. Among them were Oxford, Punjab, Delhi, Banaras, Lucknow, Allahabad, Patna, Agra and Saugar. He was awarded the title 'Padma Vibhushan' by the President of India. He was the President of the Indian Chemical Society, National Institute of Sciences of India and the Indian Science Congress. Besides them he was a member of a large number of Indian and British Societies and Academies.

He represented India on many occasions in foreign conferences. He was delegated to the British Association in 1923 and in 1932 when he attended the Michael Faraday Centenary celebrations also and to the Empire Universities Congress at Edinburgh (1931) and at Cambridge (1936). In 1945 he was a member of the Indian Scientific Mission for the Government and in 1946 leader of the official delegation of the Empire Scientific Conference. He was also a member of Indian Atomic Energy Commission which visited Great Britain in 1948 and in the same year he attended the United Nation's Scientific Conference on Utilization and Conservation of Natural Resources held in New York.

The celebration of his sixtieth birthday in February 1954 was held with a great deal of popular enthusiasm and high tributes were paid to him by Prime Minister Pandit Nehru, Sir Charles Darwin and Sir Alfred Egerton and others.

Family Life

As already mentioned he married in 1915 Shrimati Lajwanti, daughter of the headmaster of the Dyal Singh High School, Lahore, and had two sons and two daughters. His home life was a happy one. A deep shadow fell on Bhatnagar's full and active life when his wife died in 1946. In her memory he wrote a number of poems in Urdu and they are incorporated in his poetical collection named after her as 'Lajwanti'. His eldest son and daughter-in-law lived with him after his wife's death. He had built a palatial house in Lahore but it was lost to him on the partition of India in 1946. At Delhi he built a small farm outside the city which he developed with great interest hoping that he could retire there for rest, peace and quiet. But these he could not have because there was always urgent work to be done.

His death came very suddenly and took by surprise the large number of his friends and fellow-workers. After an evening meeting with scientists, he returned home to bed, had a severe heart-attack and passed away silently and quickly on 1 January 1955. He had by that time laid the foundation and erected the structure for the rapid growth of sciences in India. Referring to his sudden death the Prime Minister gave public expression to his feelings of sorrow at the Baroda session of the Indian Science Congress that was held immediately after, 'I have always been associated with many prominent figures eminent in other ways, but Dr Bhatnagar was a special combination of many things, added to which was a tremendous energy with an enthusiasm to achieve things. The result was he left a record of achievement which was truly remarkable. I can truly say that but for Dr Bhatnagar you could not have seen today the chain of national laboratories. It is sad that he should have passed away suddenly in this way. There are many things which he had discussed with me and which we hoped to put through soon. We want many more scientists like him if we are to go ahead and solve our problems.'

Scientific Work

Bhatnagar made a large number of publications. Most of them were in the field of physical chemistry and the major subjects were magneto-chemistry and physical chemistry of emulsions.

Magneto-chemistry

Though the foundations of magneto-chemistry were laid by Michael Faraday over a hundred years ago, substantial advancement of the subject has been made only during the past fifty years. Early in his career Bhatnagar realized that the application of magnetism to chemistry had great possibilities and he started his initial investigations in this field even while he was at Banaras. However his main contributions came from the Punjab University Chemical Laboratories. They covered a large number of important and complex problems in chemistry and established the usefulness of the magnetic method as a powerful tool in the hands of chemists.

The relation between physical properties and chemical constitution has been exciting interest from the early days of structural organic chemistry. What are known as colligative properties were useful for this study and were employed. That magnetic susceptibility measurements could be used for this purpose effectively, has been the main theme of Bhatnagar's contribution. He has used this method not only for the study of pure chemical compounds but also for the study of solutions, films and colloids.

Bhatnagar's results have been published in several scientific periodicals and the following are the important reviews: (i) *Physical principles and applications of magneto-chemistry* by Bhatnagar and Mathur, a book published by Macmillan and Co., Ltd, in 1935; (ii) 'A survey of recent advanecs in magnetism relating to chemistry', the Presidential Address delivered by Bhatnagar to the Chemistry section of the Jubilee session of the Indian Science Congress in 1938, and (iii) 'Some new magneto-chemical problems' by Bhatnagar and Kapur, published in *Zeitschrift fur Eletrochemie* in 1939.

To begin with there was need for an accurate method of determining the changes in diamagnetic susceptibilities that are usually quite small. Hence Bhatnagar-Mathur interference balance was designed and patented and its production was entrusted to Adam Hilger and Co, London. Besides greater degree of accuracy, it had the advantages of stability and quickness of operation. As the next step the scope of Pascal's law of additivity ($X_M = \Sigma X_A + \lambda$) was examined and dependable values for atomic and constitutive constants were obtained. It was later shown that the law could be applied not only to organic compounds but also to inorganic compounds, in which case the sum of the ionic susceptibilities gave the molecular susceptibility. A study of the effect of temperature on diamagnetic susceptibilities exhibited appreciable differences between different groups of compounds and provided a method of classification: (i) non-polar and symmetric molecules like *cyclo*hexane and carbon tetrachloride show no change, (ii) associated liquids like water and aliphatic alcohols show an increase, and (iii) aromatic compounds like benzene, toluene, xylene and a large number of other substances show decrease in susceptibility with rise of temperature. This effect was correlated with magnetic birefringence shown by the three groups of compounds.

The magnetic method was also used for the study of complex problems connected with (i) colloid formation, for example the adsorption and absorption of atmospheric gases on the surface of particles during the process of size reduction and changes in microcrystalline structure, (ii) solutions including solid solutions, (iii) atomicity of elementary molecules like those of mercury, iodine and selenium under different conditions, (iv) allotropy and (v) photochemical decompositions and phototropy. The differences between isomers of organic compounds and the nature of complex compounds, of amalgams and of ions in colourless and coloured glasses were other important topics investigated. An ingenious application was the investigation of the nature of oxide films formed on strips of copper when heated. From the paramagnetic nature of these films, it was deduced that they contained the higher oxide CuO and not Cu_2O. Another interesting piece of work was done on the relationship between magnetic fields and optical rotation. This led to an application of the method of magnetic rotation for the study of the nature of solutions of salts of higher fatty acids in water and alcohol and provided definite evidence for the existence of ionic micelles.

The relationship between chemical affinity, electricity and magnetism suggested that a magnetic field would exert some influence on the character or the speed of a chemical reaction. But earlier work on this subject provided very contradictory information. Bhatnagar and co-workers made a study of a large number of reactions of various types in and outside the magnetic field and concluded that the influence of the field depended on the difference between the sum of the molecular susceptibilities of the initial reactants and of the final products; where there was no difference the field had no effect. Further the importance of the orienting effect of the field on the atoms and ions concerned was also brought out. These considerations were used in the study of adsorption in which chemical action is involved.

Emulsions

A major portion of Bhatnagar's work concerned with emulsions which formed his main study during his stay in Donnan's laboratories in London. This subject was later on pursued in Banaras and also in Lahore. His work in this field is fully described under the head 'Bhatnagar's researches' in William Clayton's earlier book on *Emulsions and emulsification* and his later book on *Emulsions and their technical treatment*.

As a member of Donnan's school, he was engaged in the study of adhesion and cohesion in emulsions. Using emulsions of pure aniline in water under conditions wherein gravity influences are eliminated by equal densities of the two liquids, Bhatnagar observed a close similarity between such emulsions and colloidal suspensions. In each case the particles carry an electrical charge of the same order of magnitude and the limiting grain size, the potential difference data and the conditions of stability in presence of electrolytes are also similar. These observations led him to the conclusion that the electrical factors far outweigh the effects of interfacial tension.

He also made a detailed study of the volume relations in emulsions of olive oil and alkali and found that when the aqueous phase was weakly alkaline (N/1000 to N/500) the volume percentage of the oil was 74·02. With strongly alkaline aqueous phase higher ratio was possible but the product was unstable and broke up to form a stable cream having the volume ratio of oil to aqueous phase 74 to 26. The change in volume-ratio in the presence of concentrated alkalies was, according to Bhatnagar, due to the formation of a solid or gelatinous film covering the oil globules. He next made emulsions containing small globules of nearly equal size and showed that in three such emulsions made with aqueous solutions of different strengths of potassium hydroxide, the volumes of the two phases agreed with those calculated on the assumption that the closest packing existed in the emulsions.

Bhatnagar and his co-workers did an interesting piece of work on chromatic emulsions. They dispersed glycerol in acetone by the aid of collodion and obtained a milk-white emulsion. When carbon disulphide was added drop-wise to this emulsion with shaking, colours ranging from yellow to blue were obtained and the reflected colours were different. Similar addition of benzene, toluene or benzyl acetate gave colour changes in the reverse order. This phenomenon was found to be related to the relative volatilities of the two components of the external phase.

Bhatnagar made important and extensive studies on the inversion of emulsions by electrolytes, using Clayton's electrical method for detecting the inversion points; the oil-in-water type of emulsion, particularly when the aqueous phase contains small quantities of electrolytes, shows an electrical conductivity whilst the water-in-oil type does not conduct electricity. The emulsions were prepared by shaking equal volumes of paraffin oil containing 1 per cent of a long-chain fatty acid and water to which various amounts of potassium hydroxide and electrolytes had been previously added. He not only found that the emulsions can be inverted by electrolytes but also determined the exact amounts of electrolytes which caused inversion. At the critical point the ratio of potassium hydroxide to barium nitrate was 4 : 1 when the concentration of potassium hydroxide was M/10 or more and the value of the ratio increased as the concentration of the hydroxide was decreased. Further the value at the critical ratio was influenced by the nature of the acid in the oil.

He recognized that the presence of free alkali and of fatty acid made the system more complex and hence investigated the inversion of paraffin oil emulsions stabilized with soaps. This led him to the following conclusions: (i) There is a distinct effect of valency of the ions and the quantity of trivalent ions required to effect the inversion of oil-in-water emulsions is much smaller than bivalent ions. (ii) Though the nature of the soap influences the amount of electrolyte required it does not disturb the valency effect, and (iii) the amount of electrolyte necessary to effect the reversal of phases consistently increased as the volume of the aqueous phase was increased and diminished as it was reduced. A corresponding increase in the oil phase had the opposite effect. The presence of free alkali in the aqueous phase or of free fatty acid in the oil phase produced a shift in the inversion point.

In another series of studies the emulsifying agents zinc hydroxide, lead oxide and lead carbonate, casein, lecithin, egg albumin and rosin were specially prepared and purified and the results indicated that lecithin and egg albumin promoted oil-in-water type of emulsions. The addition of a small quantity of potassium hydroxide, potassium phosphate or sodium carbonate to the aqueous phase increased the stability of such emulsions, whereas the addition of acid produced inversion to the unstable water-in-oil type. A zone of instability clearly preceded the inversion. These observations led Bhatnagar to formulate the following two empirical rules: (1) A water-in-oil emulsion can be transformed into oil-in-water emulsion by electrolytes having anions like OH^-, and PO_4^{3-}, and (2) an emulsion of oil-in-water can be reversed by electrolytes having cations like H^+, Al^{3+}, Fe^{3+}, and Th^{4+}.

Bhatnagar brought the adsorption film theory of emulsions to a definite form, by laying adequate stress on the wetting of adsorbed film. According to this theory, there are no limiting concentrations of oil-in-water or vice versa, the dispersion being independent of the volumes employed. Emulsification is influenced by the mass of the emulsifying agent, the ease with which it can be adsorbed at the interfacial separating surface and the nature of ions adsorbed by the resulting film. He emphasized that the two main factors which governed the process of emulsification were (*a*) the relative wetting power of the two phases with respect to the emulsifying agent, and (*b*) surface potential of the membrane between the phases. The reversal of phase was considered to be due to changes in this membrane with respect to one or both of the above factors. He made the following generalization: 'All emulsifying agents with an excess of negative ions on them and wetted by water will yield oil-in-water emulsions while those having excess of adsorbed positive ions and wetted by oil will give water-in-oil emulsions.'

I acknowledge with gratitude help of many colleagues and friends in the collection and verification of the various details given in this memoir.

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