Animesh Chakravorty – an era of inorganic chemistry research in India

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Animesh Chakravorty (AC) is an outstanding coordination chemist and his valuable contributions have made deep impact in the field. He is a leader whose reputation is spread across the globe. AC is one of the icons among the chemists in the country. He has been a role model to his students and co-workers. AC has huge reserves of intellectual energy, scientific temperament and youthful voracity for new knowledge. He has the temperament of an artist and imaginative sensibility of a poet. In his pursuit to do quality science in general and inorganic chemistry research in particular, the principles he used, in our opinion, include the following – choose energetic ambitious people and give them intellectual freedom, show genuine interest in everyone's work and develop a personal-level interactive relationship with all members of the group, acknowledge contributions of co-workers and give due credit to younger colleagues in public, facilitate exchange of ideas with an open mind, be present in the laboratory most of the time and make himself accessible to everybody as far as possible, and engender a happy environment where people's morale is kept high. AC has been immensely successful in creating an environment in his laboratories for doing quality research with his team members and publishing steadily in international journals of repute, maintaining a nice balance between quality and quantity.

Seeds of science

AC's father Jogendra Chandra (JC) hailed from Musulli village in Mymensingh district, now in Bangladesh. JC, a brilliant student, went to study medicine in Calcutta Medical College. He was the youngest son in the family, his three elder brothers were all well-educated, and two of them became headmasters of high schools. After getting the Bachelor of Medicine degree (then called MB) from Calcutta University, JC opted to return to Mymensingh city, where he started his practice as a general physician and eye specialist. It took only a short time for his name to spread across the district. AC was born into the family of JC and Tarubala (Figure 1) on 30 June 1935 as the eldest among six siblings. JC, ever busy with his profession and other activities, always found time to sit with AC (later he would do the same with other children) during study time in the evening to help him with lessons learnt in school and with more. This exercise and the stories of medicine and science, that he narrated from time to time, deeply influenced young AC. For example, the story of Ross doing experiments with mosquitoes and malaria in Calcutta and other places, the story of the hexagonal benzene ring giving one substance after another via replacement of one group by another (a demonstration paper model of hexagon was used) and the story of the milky way being like a path strewn with stars after stars. At that age, AC could hardly understand much of these, but it all remained with him like a mysterious guiding aroma.

The early seeds of AC's interest in science were thus lovingly sowed by his father. His study was progressing well in school, first in Edward School and then in Mrityunjoy School in Mymensingh city. When he was in class eight, Bengal was partitioned. JC, then 45, decided to leave behind his lucrative practice in Mymensingh and move his family to Calcutta, as soon as possible. He knew he had to start from scratch and face hardship. But he had to do this to ensure good educational facilities for his children. The actual migration took place only in 1949 and AC got admitted in Mitra Institution in Calcutta in class ten. JC worked hard to advance his family, but later, he was trampled by ill-health.

Figure 1. Parents Jogendra Chandra and Tarubala.

When he passed away in 1975, he had the fulfilment of seeing all his children well settled as professionals in different areas. AC, then working at IIT Kanpur, became a Fellow of the Indian Academy of Sciences, Bangalore and also received the Shanti Swarup Bhatnagar Prize in Chemical Science in the same year; but the happiness got dampened with the sadness that his father was not there anymore to share the moment.

Early calls of chemistry

In the early 1950s, science was not a compulsory subject in the Matriculation curriculum of Calcutta University. It could, however, be studied as an additional subject, but most students preferred additional mathematics instead, because, they could obtain better scores in examination. AC did the same. The opportunity of systematic exposure to physics, chemistry and biology finally came in the next phase – Intermediate in Science, ISc (1950–1952) in Scottish Church College of Calcutta. The class lectures in physics and chemistry were enlivened with demonstrations of experiments. And then hands-on practical classes in all the science subjects – measuring with the screw gauge, making and collecting hydrogen gas, seeing the amoeba under the microscope and much more. The world of science started looking real exciting.

Childhood romance with chemistry had already been aroused by his father's benzene story and the stories told by teachers in school like the one on matter being made of tiny particles which lie close to one another in solids, less close in liquids and quite apart in gases. Time for studied awakening had finally arrived during ISc: elements and compounds, atoms, molecules and valency, Lavoisier, Dalton, Avogadro and others, chemical reactions, bonds and catalysis, production of ammonia, sulphuric acid and metals—it looked like a world of wonders. And the great Mendeleev and his periodic table which AC easily learnt to recite like a strange poem from memory.

He had devised a mnemonic and wrote, 'Mendeleev's epic? I have a mnemonic very easy to pick'. Later during B Sc several new books which became available augmented AC's chemical horizon. Like Finar's *Organic Chemistry* (1951) linking chemistry and reaction mechanisms and Moeller's *Inorganic Chemistry* (1952) presenting the chemistry of elements linked with structure and bonding, redox, coordination chemistry and more. AC's inclination towards inorganic chemistry started taking roots. But the soul-stirring book was Pauling's *Nature of the Chemical Bond* (2nd edn, 1948), which a dear friend Amal Sen gifted to AC to celebrate the completion of B Sc Hons at Scottish Church College.

Dawn of research: College of Science

Finally to the College of Science, University of Calcutta, for M Sc. Partly from class lectures, but mainly from readings of new books and one or two journals, specially *Journal of Chemical Education* in the library AC learnt that inorganic chemistry was in the wind of a renaissance fed by quantum bonding theories and physical methods like spectroscopy, diffraction, magnetism and more. He did not yet know much about these things, but he knew for sure that he wanted to work somewhere in the newly emerging frontiers of inorganic chemistry. But after M Sc (1957), the first thing he did was to try himself out as a teacher. At that time college lectureships were easily available and AC took up one such job, first in Manindra Chandra College soon changing to Vidyasagar College. Success in teaching ISc and B Sc classes came immediately. But that was not enough—his heart soon started pinning for doing original research.

He knew with whom he wanted to work: Sadhan Basu (SB) (1921–1992). SB was a Reader of Physical Chemistry in the College of Science, he was well-versed in polymer science, quantum chemistry and spectroscopy, and he also had some interest in inorganic chemistry. His laboratory was bubbling with students, activities and publications. AC had discussions with SB during his M Sc student days on certain principles of bonding. When AC approached for doctoral guidance, SB agreed, but after some persuasion. He was planning to do something new using the-then virgin area of the application of *ligand field theory*. SB (Figure 2) had the uncanny ability of figuring out what new could be done in an area before treading it too widely. Association with him turned out to be a crucial event in AC's career as it taught him how to proceed with something very unfamiliar in research and in the end it opened to him the gateway to state-of-the-art transition metal chemistry.

The research problem assigned was of a rare type at that time and concerned determination of single-crystal spectra of certain known complexes of copper, nickel and chromium in polarized light in the visible region and to assign the observed bands to specific ligand-field transitions on the basis of polarization selectivity. But no equipment for such measurement was in place. It had to be assembled using an old Hilger monochromator that was around, a tungsten filament lamp, a polarizing microscope with the eyepiece replaced by an IP28 amplifying tube, fitted with a locally made vacuum tube amplifier. And it finally worked! It required two persons to take readings which needed manual adjustment of the monochromator and the microscope polarizer/analyser before recording the corresponding amplifier reading. AC considers himself lucky that his classmate and dear friend Mihir Chowdhury, who was destined to become a very distinguished spectroscopist selflessly played the second man's role in most of the measurements.

Making the chosen compounds and growing millimeter-sized single crystals presented no big problem, but interpretation of the spectra in terms of *ligand field theory* was no easy task. It was only 1958 and books on ligand field theory and the relevant group theoretical principles were some years away. Learning

Figure 2. Sadhan Basu (sitting: 4th from left) and part of his research group (standing: AC and Mihir Chowdhury 1st and 2nd from left) (1960).

came only in the hard way: reading the original papers of Bethe, van Vleck, Orgel and others and *Quantum Chemistry* by Eyring, Walter and Kimball. It was real trying time, but SB was very helpful and in the end, it turned out to be an illuminating exercise for AC. The endeavour led to two communications in *Nature* on tetragonal copper complexes and one in *J. Chem. Phys.* on trigonal splitting in a chromium *tris*-chelate apart from other papers elsewhere. In authorship, SB generally put his name after those of his coworker(s), a tradition that AC followed later. The above-mentioned papers became part of the doctoral thesis of AC (Ph D, 1961). And all along, AC preserved a dual identity by shuttling between College of Science (researcher) and nearby Vidyasagar College (lecturer)! The energy to do both must have come from his love for both research and teaching. And he might have been convinced that the opportunity to do both under the same roof, would arrive one day.

After submitting the doctoral thesis, AC was poised for doing some worthwhile research independently. SB was supportive of such efforts by students. AC zeroed in on a problem relating to gold chemistry that resulted in the first-ever report and analysis of ligand-to-metal charge-transfer spectra in square planar halo- and related complexes in *J. Chem. Phys.* The coauthor, a classmate doing Ph D in colloid chemistry, provided generous access to AC to use the new Beckman DU spectrophotometer in his laboratory. Gold used for making the complexes consisted of bits and pieces of broken ornaments gifted by AC's mother. AC says that the Ph D work helped him to toddle and his mother's gold helped him to stand upright. He was then 26.

Before we conclude this section, a mention of one other activity of the period must be made. From early years, AC was fond of literature and he mildly nourished the desire to become a writer. What he eventually did, was to publish numerous articles on diverse science-related topics frequently in popular Bengali literary magazines and the magazine section of Sunday newspapers between 1958 and 1961. This activity made his name locally quite familiar. Later when he went to USA, he continued this activity for some time and also contributed a serial titled *Washingtoner Chithi* (Letter

from Washington) in a magazine. However, the demand of research work, soon put a near-stop on this activity. I had the joy of going through a private collection of the articles preserved in a book form.

MIT and Harvard

Time had come to change, to expand the horizon of ideas and techniques and to feel the pulse of inorganic research in some top laboratories. The work with SB had caught the attention and F. A. Cotton, then at MIT, who promptly offered AC a postdoctoral fellowship. Cotton's doctoral mentor G. Wilkinson (Nobel Prize 1973) did the same from Imperial College, London. AC met Wilkinson in London many years later, but accepted Cotton's offer and joined his group in the end of September 1961. Sweet memories of the laboratory and college in Calcutta lingered on and living alone away from parents for the first time was a pain. Cotton was then 31 and his reputation as an innovative researcher and author, was ascending rapidly. AC tried his hand at several themes, but the most substantive activity published in *J. Phys. Chem.* concerned solution stability constants and structures of 3D metal complexes of certain imidazole derivatives. This work which was well received had biological significance.

Cotton was a busy man but was also social and friendly. Outside the laboratory, there were lighter moments and parties. A latent friendship probably grew between the two. Twenty years later in the early 1980's, Cotton re-established contact with AC who was then at Indian Association for the Cultivation of Science (IACS), suggesting joint redox and structural work. Finally in 1983 AC was persuaded to spend a few months as a visiting Professor at Texas A&M University, where Cotton was then located. Structures of a number of compounds from AC's laboratory were solved resulting in a number of joint papers. AC closely examined the functioning of modern diffractometers. On return to India he could finally get a diffractometer facility set up in late 1980s at IACS which brought about a sea change to the chemistry of his group. While in Texas A&M, AC visited and lectured in many major universities and institutes in USA. He also addressed a MIT-Harvard joint-colloquium and gave talks at the Imperial College and Cambridge University on his way back to India. In later years AC met Cotton a few more times in international conferences. When AC received the TWAS Prize in Chemical Science (1994). Cotton wrote a tribute which ended thus, 'The scale and sophistication of Chakravorty's work will stand comparison with the best work in coordination chemistry anywhere in the world.' With Cotton's unexpected passing in 2007 (*Current Science,* 2007, **92**, 844) AC like many others, lost a dear friend and a genuine well-wisher. Cotton was a Foreign Fellow of INSA and was very happy about it.

Towards the end of 1962 AC shifted from MIT to Harvard, at the suggestion of Cotton. At Harvard his mentor was Cotton's former student R. H. Holm, then 29, who was at the initial phase of his independent career. There were one or two Ph D students in the laboratory and AC was the only post-doctoral fellow. The problem Holm assigned was on stereo-labile nickel complexes, a relatively new area at that time. It involved considerable amount of synthetic work (in one case advice from R. B. Woodward had to be taken), resolution of racemic amines scrutiny of the nature of stereo-lability and unpaired spin-density distribution over the ligand, using among other things variable-temperature contact-shifted ^{1}H NMR spectra, an exciting novelty at that time. A particularly noteworthy early finding was the detection of paramagnetic diastereoisomers by NMR spectroscopy.

Learning many new things and getting commensurate results from hard work, it was an exciting time for AC. The day in the laboratory usually ended at nine or ten at night and Holm on his way back to home would almost invariably give a ride to AC to his apartment. A lasting friendship had developed between the two. The results of the above work have been chronicled in more than half-a-dozen major joint papers that brought the first trickle of fame to Holm. AC was also able to do and publish independent work on anomalous isomorphism which was later elaborated by others as structure mimicry. Holm and AC had also started writing their acclaimed critical review article on Schiff base complexes, which was completed and published in *Prog. Inorg. Chem.*, after AC had moved to IIT Kanpur. Eventually Holm became a pioneer of bioinorganic chemistry, but the two men remained in contact and met a few times during AC's visits to USA and in international conferences.

The three years in USA passed like a flash for AC: groping, searching, learning, working and on the way making friends some of whom became pioneers; taking to heart the work culture and single-minded dedication he witnessed and seeing the bounty of Nature in the well preserved national parks and museums spread all over the country. Also seeing the miseries like that of segregation which AC himself faced on a trip to the south. All included, it was a real fruitful time that contributed in shaping AC's way of thinking and doing things.

Holm, with whom I did postdoctoral work many years later, recently wrote this tribute '…I was enormously fortunate to be able to offer a position to Animesh, who was of great assistance in starting my laboratory. His work at Harvard (1962–64) focused on problems in static and dynamical in inorganic chemistry and was particularly noteworthy because of investigations of the ^{1}H NMR spectra of paramagnetic molecules, a relatively new subject at the time. Little if anything in those studies requires revision today. It became quickly evident that Animesh's scientific intellect and predilection toward meticulous experimentation would set a high standard for his independent work. Such is evident to his colleagues in India and, indeed, throughout the world where he stands as one of the leaders in inorganic coordination chemistry.'

IIT Kanpur

On a pleasant December afternoon in 1964, AC then 29, reached IIT Kanpur to join the Chemistry Department. Established in 1962 with American collaboration, the two-year old Institute then had only western and southern buildings standing to house most activities. The library was in a workshop shed. The Chemistry Department was already in a marching tempo. There was something in the air—a promise, a destiny, sign of an impending starburst. The faculty and number of doctoral students grew steadily and the faculty list soon read like this: C. N. R. Rao, M. V. George, P. T. Narasimhan, P. S. Goel, A. Chakravorty, J. C. Ahluwalia, D. Devaprabhakara, U. C. Agarwala, S. Ranganathan, G. Mehta,

D. Balasubramanian, P. T. Manoharan and more. The leadership of the Departmental Head, C. N. R. Rao played a vital role in shaping the department as a symbol of excellence. The rest is history.

After arrival AC soon had a staff quarter to live, two working benches to do research in a shared room, a small attached table as 'office', a small fund, two research scholars, general chemistry (for engineers) and advanced inorganic chemistry (for doctoral students) to teach … thus began the lonesome, but busy journey into the future. And things looked brighter as days went by: more students, more space, more funding, publications, new teaching courses to develop, recognition by peers in India and abroad…. With the spectral facilities like UV-vis, IR and proton NMR already available and the magnetic balance AC had set up, his group (Figure 3) started working on synthetic and stereochemical problems of new types of complexes, including the then uncommon pentacoordinated species. The group deftly used the NMR technique for stereochemical characterization and demonstrated that suitably positioned aromatic chloro groups can act as weak coordination sites triggering stereochemical equilibria in solutions. The activity matured with increasing tempo over ten years or so. A major recognition, an Academy Fellowship and an Editorial Board Membership of a major journal had arrived. AC was happy, but was pining now for something different and exciting.

Partly by design and partly by serendipity, the break came while examining certain new variable-valent nickel complexes. AC realized that for proper understanding of these systems cyclic voltametric studies were essential. But this was no standard technique at that time and the required equipment was not accessible. AC decided to build it along with his student Joy Gopal Mohanty, who had an amateur interest in electronics. He also took advice from an electrical engineer friend about circuit boards layouts. The equipment (Figure 4) was ready for use within a year. This event was a watershed in making redox phenomena and oxidation-state manipulation as widely recognized hallmarks of his research group.

By the early 1970s the Chemistry Department at IIT Kanpur, became a highly reputed place of scholarship and frontier research. A congenial ambience, outstanding colleagues, dedicated and questioning students, regular seminars and talks by distinguished outsiders – it was an experience. Prizes and other forms of recognition had started arriving to colleagues at frequent intervals and they celebrated and speculated whose turn it will be next. This tempo continued into the mid-1970s, when it was also time for some colleagues to bid goodbye to IIT Kanpur and go elsewhere for playing an even bigger role in science. It was as though IIT Kanpur was preparing to fan out to other parts of the country.

After spending the first two years alone in Kanpur, AC got married to Aparna (we call her 'Boudi') in 1966. AC was ever busy with his work and with his students as usual and it was Boudi who looked after everything in the house, most importantly upbringing of the children (son, Ananda and daughter Shohini, born in 1968 and 1972 respectively). She became a model homemaker who had sacrificed her desires to have a career of her own for the sake of her family. In mid-1970s, AC started getting attractive offers from other reputed places. Finally in June 1977 (AC was then Head of the Chemistry Department) the family left Kanpur for Kolkata, with all the sweet memories of action-filled years. AC had been persuaded by friends and well wishers to join IACS as Head of the Inorganic Chemistry Department. He was 42.

Figure 3. The early research group at IIT Kanpur (1967).

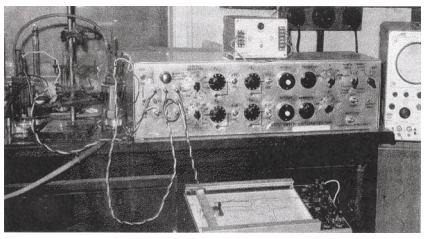

Figure 4. The home-built cyclic voltameter (1975).

IACS

Founded in 1876, IACS had a history of high reputation in physics, the moment of crowning glory being the discovery of Raman Effect. The chemistry departments were added only around 1950. Coming from teen-aged IIT Kanpur, it took some effort for AC to retune to century-old ways of IACS. A pleasant feature was the presence of two old friends (Usha Ranjan Ghatak and Mihir Chowdhury) as the Heads of Organic and Physical Chemistry departments respectively. AC's laboratory needed a lot of redoing and start of normal activity took some time. A few students had migrated from IIT Kanpur with AC to complete their work.

IACS was supported by government funds, but allocation for new major equipment was limited. For quick progress, funds had to be raised through individual projects. The home-built cyclic voltameter had served its purpose and now AC needed a commercially available multifunction system. The first project to DST was written accordingly. Some years later a second and then a third and so on – AC's group went from work to work and from project to project. Most of the equipment needed were brought in this manner. Publications in major journals came into full stream from early 1980s. This could be sustained for years, because as AC says, 'soon after coming to IACS a very pleasant thing started happening: bright young students with excellent career records started coming to join the group for doctoral work one after another' (Figure 5). Akhil Ranjan Chakravarty was the first to join, followed by Dipankar Datta and I was third. Soon it became a tradition for AC's laboratory to remain full to the brim with students and their work.

Before we proceed to other issues, one or two items that much influenced the chemistry community in the country, need be noted. In December 1985, a three-day INSA Golden Jubilee Symposium on 'Recent Trends in Inorganic Chemistry' (RTIC) was convened by AC at IACS. There were nearly 130 partici-

pants and 30 or so lectures (Figure 6) were published by INSA as a volume in July 1986. AC wrote the preface for the volume with a vision 'Inorganic chemistry is one of the three traditional branches of chemistry. Yet during the last three decades or so this branch has undergone unprecedented metamorphosis. The availability of sophisticated experimental tools and theoretical methods added many new dimensions to this area. The robust roots of structure and reactivity have spread deep into its foundation. Symbolic of these developments is the ever fruitful and progressive interplay of inorganic chemistry with other areas such as organic chemistry, biology, physics and the science of the solid state. Today inorganic chemistry stands at the confluence of many disciplines. We thought that the best way to bring home some of these points would be to hold a three-day Symposium on Recent Trends in Inorganic Chemistry as part of the Golden Jubilee Celebrations of the Academy … Works of all active groups cannot be covered in one single symposium and the present symposium is no exception. Nevertheless, this volume is believed to be a good reckoner of inorganic chemistry, particularly as it is being done in India. It may also help us to find the voids that need to be filled and the inadequacies that need serious attention. We must do better and better inorganic chemistry and signs as seen in this volume are certainly encouraging.'

Figure 5. The early research group at IACS Kolkata (1978).

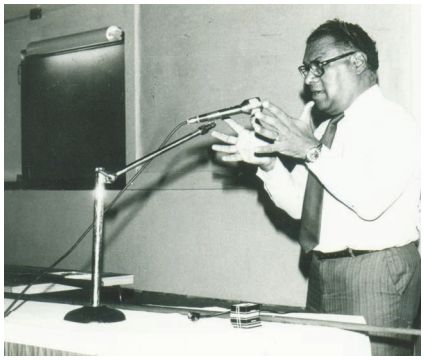

Figure 6. The Inaugural Lecture ('Novel Metal Oxides') by C. N. R. Rao at the conference on 'Recent Trends in Inorganic Chemistry' held at IACS (1985).

The vision survived and 'Recent Trends in Inorganic Chemistry' remained alive and flourished with the slightly changed name, 'Modern Trends in Inorganic Chemistry' (MTIC). It is a major chemistry conference in the country held every two years moving from one venue to another (MTIC XVI is scheduled in 2015). One other thing that pleased AC immensely was the creation of the Programme Advisory Committee (PAC) in Inorganic Chemistry by DST for research and related funding to this area of chemistry benefitting generations of inorganic chemists in their pursuits.

AC formally retired from IACS in 2000 when he turned sixty-five. He was not taking any salary from IACS from 1996 when he was awarded the INSA Golden Jubilee Research Professorship for five years. After that, he held other positions like the Hindustan Lever Research Professorship of JNCASR and is now the Tata Chemicals Distinguished Emeritus Professor of Inorganic Chemistry (created for two years by Tata Chemicals to mark their Platinum Jubilee)—all tenable at IACS where he is also an Emeritus Professor of the Institute. Prevalent circumstance prompted him to stop taking students after 2001 and the last student submitted his doctoral thesis in 2006.

AC has had a long standing interest in the history of chemistry and in popularization of chemistry through lectures and writings. He published a series of biographies of legendary chemists in *Resonance*. He lectured regularly in schools, colleges and institutes on the nature, importance and beauty of chemistry. His lecture ('A small chemistry canvas') and interaction with school children at the 33rd International Chemistry Olympiad in 2001 in Mumbai, where I was also present, remains a memorable event. AC is a stylish and incisive orator. During the last few years, he has talked and written extensively, on the life and work of P. C. Rây, the father of Indian chemistry. He was a key speaker when the first ever Chemical Landmark Plaque outside Europe was installed in Calcutta by Royal Society of Chemistry to honour Rây. He is publishing a series of articles in *J. Indian Chem. Soc*., critically examining the vast research contributions of Rây in the context of later work by others. For this he authenticates Rây's experiments as required by repeating them, determining concerned structures and more at IACS. Thus he has authenticated Rây's mercurous nitrite and triiodomercuric anion which represented the first example of transition metal tricoordination. He keenly desires to prepare a critical document on Indian contributions to the progress of inorganic chemistry.

At IIT Kanpur he had become a Bhatnagar Prize awardee and a Fellow of the Indian Academy of Sciences and at IACS, AC became a Fellow of INSA and of TWAS, which had previously honoured him with the Prize in Chemical Sciences. He was awarded a number of Medals of different learned bodies as well as numerous endowment lectureships. Both Indian Chemical Society and Chemical Research Society of India honoured him with Gold Medals for lifetime achievement (Figure 7). An honorary doctorate degree (D Sc, *Honoris Causa*) was bestowed on him by Burdwan University and he held the first Nehru Chair in Chemistry at Hyderabad University. He was a Bureau Member of IUPAC of which he is now an Honorary Fellow. He is a past President of the Chemical Research Society of India. AC has been on the Editorial Boards of a number of international journals and volumes including *Inorganica Chimica Acta*, *Dalton Transactions*, *Inorganic Chemistry* and *Comprehensive Coordination Chemistry* (2nd edn).

He has lectured extensively abroad in conferences and in university or institute departments. A personal recollection: the seven-member INSA delegation at the Indo-Russian joint symposium on

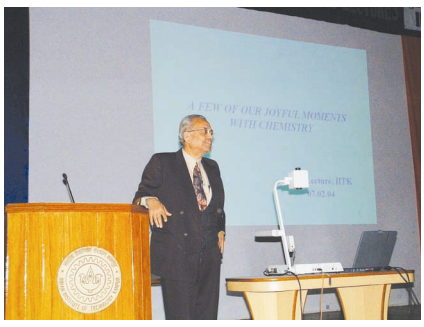

Figure 7. AC presenting 'Chemical Research Society of India' Gold Medal Receiving Lecture at IIT Kanpur (2004).

Figure 8. INSA delegation led by AC to Indo-Russian Symposium on 'Inorganic and Organometallic Chemistry' held in Russia (1993).

organometallic and inorganic chemistry in Russia in 1993 (Figure 8). It was led by AC and the leader of the Russian side was the very famous chemist M. E. Vol'pin. Then at IIT Kanpur, I was the youngest member of the Indian side. Many of the lectures were held in a boat cruising along river Volga. It was near winter and the cold outside was biting and AC moved from cabin to cabin to see that all are comfortable. Everything included, it remains an unforgettable experience in science and more. Later Vol'pin visited and lectured at IACS and other institutes in India.

To conclude this section let me say a few words about certain events organized by the chemistry community to highlight AC's contributions. In 1995 the Indian Academy of Sciences brought out an issue of the *Proceedings* (*Chem. Sci.*) (1995, **107**, 245–518)) to honour AC on the occasion of his sixtieth birth anniversary. The Guest Editors D. Datta and K. Nag noted that AC 'has made pioneering contributions in the area of inorganic chemistry in the country'. The issue had about 24 papers covering a wide cross-section of topics in inorganic chemistry in different major laboratories in the country. In December 1995, a widely attended three-day National Symposium on 'Perspectives of Inorganic Chemistry' dedicated to AC was held at IACS (Figure 9). In 2010 when AC turned 75, *Inorg. Chim. Acta* published a special volume (2010, **363**, 2693–3138) dedicated to him. The volume had more than 60 papers; many of them from major laboratories abroad. Some of the material in the preface to the volume helped in writing this essay.

Some views from my window

First a few general comments about AC's research. One thing that stands out is that he has been interested in and worked on intellectually challenging problems right from his graduate student days in late fifties. AC had a mind of his own and the courage to seek things new and unfamiliar, thanks to his association with stalwarts in his doctoral and postdoctoral days. He was different from his peers in his choice of research problems. All through his career, he looked for trends and generalizations, with a sizeable number of quality publications in internationally acclaimed journals, on a particular theme of research. He seemed to have a constant stream of new ideas that were very timely or ahead of the times. In science the real measure of one's work, is in creativity. On this count his contributions certainly stand among the best.

He displayed unique qualities in dealing with his Ph D students and in giving them a feeling of being a part of his extended family. What amazed his students was his ability to see through a research problem to the very end of it. He could calmly analyse the different aspects of the project, assess the kind of output that can be obtained by pursuing it, and guide on how to go about it. He is a person with an unusual vision! AC not only gave his Ph D students excellent training as researchers, but also successfully induced in their hearts the thirst for high class research. He pushed his students hard to develop adequate experimental skill and remain well-informed about the latest in our research-field. He was very strict in getting things done by them the way he wanted, but he never was rude with his students. Before leaving the laboratory in the evening, he used to have a chat with all his group members encouraging them towards progress. He acknowledged and congratulated students when he was informed of any good piece of result. To all his students AC is, in the true spirit, a member of the family. Students did not feel that they worked for him, they felt that they worked with him. This aroused them greatly and chemistry appeared challenging, stimulating, and a lot of fun in one go. He was very nurturing and supportive to many of his students. He appealed to our better instincts and made us want to live up to his expectations. In essence, he is a great mentor to work with. No doubt he was a hard taskmaster, but through his dedicated research efforts, he was instrumental in shaping the minds of his students to achieve a high degree of science-practice-culture. It is no wonder that he succeeded in spawning such a vibrant school for doing state-of-the-art research in inorganic chemistry.

I feel like mentioning my first acquaintance with his work and my first interaction with him. I came to know about his work with Richard Holm by one of my finest teachers—R. L. Dutta—during my M Sc days at the Department of Chemistry of University of Burdwan. I saw AC first when he visited our department in early 1978 to deliver a lecture. My direct interaction with AC was in September 1978, when I was selected as a research fellow in the Department of Inorganic Chemistry, IACS. I was simply charged by his professional charisma. This led my entry to the professional world, starting as a Ph D student in his laboratory.

It has indeed been an overwhelming experience to be associated with a person like him. It will be appropriate to quote talking about us! In a recent informal congregation of 'Friends of Inorganic Chemistry (FOIC)' on 21 December 2008 consisting of generations of chemists mentored by him, he said this. 'I have been blessed with torrents of enthu-

Figure 9. A group photo of some of his students present during the National Symposium held at IACS when AC became sixty (1995).

siasm in the form of students with whom I felt as one. And as one we could do things that I could not imagine alone. I now greatly rejoice in finding them and their students spread across academies and industries doing wonderful things of their own. Is it not like an evergreen tree with a perpetually dilating canopy?'

Needless to say that AC contributed enormously to the growth of modern coordination chemistry research in India. He has been successful in establishing a 'gharana' for doing state-of-the-art research. His body of work has truly impacted modern inorganic chemistry in more than one way. Through their independent efforts, a large number of his Ph D students are pursuing research at the cutting-edge across the country.

Fifty eight students have done their doctoral work under AC's supervision. He has published over 300 research papers, nearly 20 review articles, and book chapters. We adore him not only for his outstanding scientific achievements, but also as a really genuine person, a wonderful human being, a friend and philosopher. To pay respect to AC, his students initiated an 'Animesh Chakravorty Endowment Lecture' series in 2006, an event that happens every two years under the aegis of the Chemical Research Society of India. The first of this series was at IIT Bombay, delivered by Karl Wieghardt of Max-Planck Institute for Bioinorganic Chemistry. This was followed by Edward I Solomon of Stanford University; Jan Reedijk of Leiden University, Franc Meyer, Institut für Anorganische Chemie Georg-August-Universität Göttingen and William B Tolman of the University of Minnesota, Minneapolis.

Allow me to add one or two more things. My wife and I had joined AC's family in travelling to many tourist spots in West Bengal and India. On such occasions, it was a great experience for me to closely interact with AC. I must also express my deepest regards and gratefulness to him for being with me during the crucial times of three major surgeries which I had to undergo over the years in Kolkata. He and his family stood by me and my family as a pillar of support.

Now, a few words about Aparna Chakravorty (Boudi), the life partner of AC (Figure 10). She has been the pillar of strength, dedication and support for AC all along. I personally feel very fortunate to be a member of AC's extended family. I have been interacting with his family members for more than 35 years now and Boudi played a major role in giving me a feeling that I am her family member. All of us have been moved by his great ability in providing timely advice on diverse issues. On a personal count, I should say that it has been the most fascinating and rewarding journey with him. AC and Boudi have lived outstandingly well and we wish them all the very best in days ahead.

Some flavours of the chemistry

In outlining AC's scientific contributions, many thoughts and images crowd my mind. His approach to research has been deceptively simple: design and synthesis of *relevant* and interesting molecules, scrutiny of *desired* properties, and reactivity in terms of structure. Yet from this platform, he contributed enormously to the growth of modern coordination chemistry research in India, noticed round the world, as is particularly highlighted by the editorial assignments in top international journals bestowed on him. The ability to make progress on initially unfamiliar terrains – be it methodology or a chemical phenomenon – is grained into his nature. AC focused his research primarily on the structural and reactivity aspects of transition-element compounds. For characterizing newly synthesized complexes, AC moved seamlessly from ^{1}H NMR spectroscopy to electrochemical methods to EPR spectroscopy to single-crystal X-ray structure determination and more.

Figure 10. Boudi and AC greeting the participants during inauguration of the international symposium, 'Frontiers in Inorganic Chemistry – 2010' organized at IACS to honour AC on his seventy-fifth birth anniversary (2010).

Chemical and electrochemical manipulation of metal and ligand oxidation states and scrutiny of associated redox phenomena, have been one of the main hallmarks of the group. He was a pioneer in the fruitful use of now-commonplace cyclic voltammetry and coulometry in elucidation of variable-valence inorganic chemistry. This activity started in IIT Kanpur with certain oxime complexes of nickel and later others used the compounds extensively as redox reagents in their work. In the meantime AC moved away to do other things on nickel oxidation states, such as the effect of sulfur-ligation on redox potency of relevance to hydrogenases, reduction potentials of hexaaquo species, and more. Oxime ligands were also used in two-atom bridging to construct the first linear trinuclear systems, incorporating mixed-valence/spin in the form of $Fe^{II}Fe^{III}Fe^{II}$ and $Mn^{II}Mn^{II}Mn^{II}$. In these systems the terminal (low-spin) and central (high-spin) atoms are respectively N- and O-coordinated. The Fe cluster afforded new polynuclear families via alkali-promoted extrusion of the central iron atom and subsequent reassembly. The triangular copper core $Cu_3^{II}X$ held by oximato bridging was shown to undergo facile one-electron oxidation (X = O) or reduction (X = OH) generating mixed-valency; the proton acting in a valve-like fashion regulating the direction of electron flow. Such species are relevant in the context of copper-promoted redox in biology.

The large body of work on ruthenium and osmium that was to emerge in due course from AC's group, was initiated by Akhil, and Sreebrata Goswami and myself. It took time to figure out the right starting materials and synthetic tricks. And therefore, the first publications were painfully slow to materialize. Then we found the mist abating and as the chemistry spread, it began to look like a banner of the group. We cite the works on electronic structure and distortion parameters of trivalent O,N,S,P-coordinated complexes, as revealed by EPR and UV-vis-NIR spectra, taken in conjunction with d^5 *g*-tensor theory, on the generalities of isomer preference of oxidation states

specially in $MS_4P_2^z$ systems shuttling between bivalency and trivalency, on the first systematic design of azobenzene cyclometalates of trivalent ruthenium, and on the assembly of an unprecedented four-membered zwitterionic metalacycle system via decarbonylation of diformyl Schiff bases and its fascinating reactions, including facile insertion of carbon monoxide, alkynes, and isonitriles. AC's pioneering work on complexes of π-acidic azopyridines, which promote lower metal and ligand oxidation levels, opened up an opportunity for future work by many. His findings include oxidants catalysing water oxidation, stable azo-anion radical complexes, serial ligand-redox, spectroelectrochemical correlations and many more.

When AC was found showering praise on his students, standing in the middle of the laboratory, everybody knew that something good has happened. This is the way the conversion of palladated-azobenzenes to azophenol complexes by organic peracids was declared. The peracids performed electrophilic Oxygen Atom Transfer (OAT) into the Pd–C bond via heterolytic O–O cleavage in an associative transition state. Interestingly, the corresponding Pt–C bond was unreactive, instead the metal was oxidized generating the first family of Pt(IV)-azobenzene cyclometalates. An intriguing example of OAT is the aerial *o*-hydroxylation of a pendant aryl group in azopyridine complexes of palladium in alkaline media.

In the recent past, AC had been extensively involved with variable-valent rhenium chemistry of conjugated nitrogenous ligands. Many of the $Re^{V}O$ species displayed associative OAT to tertiary phosphines via nucleophilic PR_3 attack on the metal-oxo bond, finally affording $Re^{III}(OPR_3)$. A single atom transfer to ditertiary phosphines brought to play a fascinating spacer-dependent twin isomerization (linkage and geometrical). A remarkable rhenium-promoted OAT reaction was shown to convert imine to amide, following metal oxidation in wet media, the amide oxygen originating from water via its addition to the imine group.

The oxorhenium work noted above, reminds us of AC's early work on an oxygenase-inspired model dioxomolybdenum system with one active site, which has attracted attention for decades. In recent years, he enriched oxovanadium chemistry with illuminating studies on valence-delocalization in mixed systems, chiral vanadate esters of diols, triols and modified carbohydrates, catecholase action of catechol esters, solvent-controlled supramolecular architecture and coordination geometry, and more. He was specially invited to speak on this work at the International Conference on Vanadium Chemistry in Osaka University in 2003.

In conclusion

Obviously, it is not possible to touch upon all aspects of AC's multi-faceted personality and his contributions to inorganic coordination chemistry research. This essay is an attempt to portray the journey of a legendary inorganic chemist, who has made immense impact on the career development of many inorganic chemists. Like many other practising scientists of our country, I do believe that AC is a true trend-setter of modern inorganic chemistry research in India. He introduced and popularized the practice of rapid-sweep voltammetry in transition metal chemistry. It has now become one of the primary tools of characterization of redox-initiated chemical reactions. A quality, which has singularly inspired his associates and students is his devotion and commitment to work. The scientific community will acknowledge his insightful advice and AC will always be remembered by his students for his creative mentorship. AC continues to serve the chemistry fraternity in many ways, shouldering responsibilities as they come.

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